Book of abstracts

5th International Conference on Smart Energy Systems in Copenhagen, on 10-11 September 2019.

Lund, Henrik; Mathiesen, Brian Vad; Østergaard, Poul Alberg

5TH INTERNATIONAL CONFERENCE ON SMART ENERGY SYSTEMS

BOOK OF ABSTRACTS

AALBORG UNIVERSITY
DENMARK

sEEnergies

reINVEST

4DH

Innovation Fund Denmark

UN environment

DISTRICT ENERGY IN CITIES INITIATIVE

Fonden Energi- & Miljødata
www.emdfonden.dk

Copenhagen, 10-11 September 2019

5th International Conference on Smart Energy Systems
10-11 September 2019

Book of Abstracts

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Department of Planning
Rendsburggade 14
9000 Aalborg
Print: Vester Kopi

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Frontpage photos:
May-Britt Vestergaard Knudsen

Preface

It is a great pleasure to welcome you to the **5th International Conference on Smart Energy Systems** in Copenhagen, on 10-11 September 2019.

The conference is organised by Aalborg University – powered by the RE-Invest and sEEnergies projects, the UN Environment District Energy in Cities Initiative, Innovation Fund Denmark and Fonden Energi- og Miljødata. The Conference is sponsored by Danfoss, Kamstrup, COWI and Euroheat & Power/DHC+.

After last year's success in Aalborg with 150 presentations and more than 300 participants, we are indeed happy to be able to welcome you to this year's conference in Copenhagen with 180 presentations and a number of side events. The 5th conference in the series cements it as a main venue for presentations and fruitful debates on subjects that are pertinent to the development and implementation of smart energy systems to fulfil national and international objectives. Once again, we welcome more than 300 participants from more than 30 countries around the world. We wish to thank everyone for your valuable contributions.

The 5th International Conference on SES has an expanded focus with new topics within smart energy systems, sustainable energy, electrification of the heat and transport sectors, electrofuels and energy efficiency. The aim of the conference is to establish a forum for presenting and discussing scientific findings and industrial experiences related to the subject of smart energy systems based on renewable energy, 4th Generation District Heating Technologies and Systems (4GDH), electrification of heating and transport sectors, electrofuels and energy efficiency.

The Smart Energy System approach was defined in 2011 in the CEESA project. The project addressed Danish scenarios with a particular focus on renewable energy in the transport system in a context with limited access to bioenergy. The Smart Energy System concept is essential for 100% renewable energy systems to harvest storage synergies and exploit low-value heat sources. The most effective and least-cost solutions are to be found when the electricity sector is combined with the heating and cooling sectors and/or the transport sector. Moreover, the combination of electricity and gas infrastructures may play an important role in the design of future renewable energy systems.

In future energy systems, combinations of low-temperature district heating resources and heat savings represent a promising alternative to individual heating solutions and passive or energy+ buildings. This change in the heating system also requires institutional and organisational changes that address the implementation of new technologies and enable new markets that can provide feasible solutions to society. All presentations, discussions, talks and debates during the conferences contribute to the understanding and development of future energy systems.

We wish you all a fruitful conference,

Henrik Lund, Brian Vad Mathiesen and Poul Alberg Østergaard
Professors at Aalborg University and Conference organisers

Table of Contents

5TH INTERNATIONAL CONFERENCE ON

Smart Energy Systems

4th Generation District Heating, Electrification, Electrofuels and Energy Efficiency

10-11 SEPT 2019 · COPENHAGEN

AALBORG UNIVERSITY
DENMARK

Call for abstracts

The Smart Energy System concept is essential for cost-effective 100% renewable energy systems. The concept includes a focus on energy efficiency, end use savings and sector integration to establish energy system flexibility, harvest synergies by using all infrastructures and lower energy storage cost.

As opposed to, for instance, the smart grid concept, which takes a sole focus on the electricity sector, the smart energy systems approach includes the entire energy system in its identification of suitable energy infrastructure designs and operation strategies. Focusing solely on the smart electricity grid often leads to the definition of transmission lines, flexible electricity demands, and electricity storage as the primary means of dealing with the integration of fluctuating renewable sources. However, these measures are neither very effective nor cost-efficient considering the nature of wind power and similar sources. The most effective and least-costly solutions are to be found when the electricity sector is combined with the heating and cooling sectors and/or the transport sector. Moreover, the combination of electricity and gas infrastructures may play an important role in the design of future renewable energy systems, and the electrification of heating and transport – possibly through electrofuels – can play a pivotal role in providing flexibility and ensuring renewable energy integration in all sectors.

In future energy systems, energy savings and 4th generation district heating can be combined, creating significant benefits. Low-temperature district heat sources, renewable energy heat sources combined with heat savings represent a promising pathway as opposed to individual heating solutions and passive or energy+ buildings in urban areas. Electrification in combination with district heat is a very important driver to eliminate fossil fuels. Power heat, power to gas and power to liquid together with energy efficiency and 4th generation district heating create a flexible smart energy system. These changes towards integrated smart energy systems and 4th generation district heating also require institutional and organisational changes that address the implementation of new technologies and enable new markets to provide feasible solutions to society.

Important Dates 2019

8 April - Deadline for submission of abstracts for speakers (**NB** Additional upgrade to paper is optional)

8 May - Reply on acceptance of abstracts

31 May - Early registration deadline

10-11 September - Conference

1 May - 31 August Registration is open

Topics

Smart energy system analyses, tools and methodologies

Smart energy infrastructure and storage options

Integrated energy systems and smart grids

Institutional and organisational change for smart energy systems and radical technological change

Energy savings, in the electricity sector, in buildings and transport as well as within industry

4th generation district heating concepts, future district heating production and systems

Electrification of transport, heating and industry

The production, technologies for and use of electrofuels in future energy systems

Planning and organisational challenges for smart energy systems and district heating

Geographical information systems (GIS) for energy systems, heat planning and district heating

Components and systems for district heating, energy efficiency, electrification and electrofuels

Renewable energy sources and waste heat sources for district heating

Fee including materials, coffee, lunches:

- Normal fee: **400 EUR**
- Early registration (for presenters with accepted abstracts): **300 EUR**

reINVEST sEEnergies 4DH Innovation Fund Denmark

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10-11 SEPT 2019 · COPENHAGEN

AALBORG UNIVERSITY
DENMARK

Photos by May-Britt Vestergaard Knudsen

Aim and Organisers

The aim of the conference is to establish a venue for presenting and discussing scientific findings and industrial experiences related to the subject of Smart Energy Systems based on renewable energy, 4th Generation District Heating Technologies and Systems (4GDH), electrification of heating and transport sectors, electro fuels and energy efficiency.

This 5th conference in the series cements it as a main venue for presentations and fruitful debates on subjects that are pertinent to the development and implementation of smart energy systems to fulfil national and international objectives.

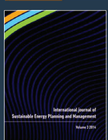
The conference is organised by Aalborg University, the RE-INVEST and the sEEnergies projects.

- RE-INVEST is an international research project, which develops robust and cost-effective renewable energy investment strategies for Denmark and Europe funded by Innovation Fund Denmark.
- sEEnergies is a European research project focusing on Smart Energy Systems and supply chain effects on energy efficiency in all sectors and infrastructure funded by Horizon 2020.

Submission Procedure

Both scientific and industrial contributions to the conference are most welcome. Submitted abstracts will be reviewed by a scientific and an industrial committee. Authors of approved abstracts will be invited to submit papers to special issues of Energy, IJSEPM and Energies. Abstracts may be presented at the conference without uploading full paper, as this is not a requirement.

energies



Best Presentation Awards will be given to a selected number of presenters at the conference.

Please upload your one-page abstract here: **www.smartenergysystems.eu** before 8 April 2019

International Scientific Committee

Prof. Dagnija Blumberga, Riga Technical University, Latvia
Dr. Robin Wiltshire, Building Research Establishment (BRE), UK
Dr. Anton Ianakiev, Nottingham Trent University
Dr. Ralf-Roman Schmidt, Austrian Institute of Technology, Austria
Dr. Hanne L. Raadal, Østfold Research, Norway
Dr. Richard van Leeuwen, Saxion University, The Netherlands
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Conference Chairs

Prof. Henrik Lund, Prof. Brian Vad Mathiesen, Prof. Poul Alberg Østergaard, Aalborg University, Denmark

Further information

www.smartenergysystems.eu

5TH INTERNATIONAL CONFERENCE ON

Smart Energy Systems

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10-11 SEPT 2019 • COPENHAGEN

AALBORG UNIVERSITY
DENMARK

PROGRAMME

Monday 9 September 2019

#SESAAU2019

Smart Energy System Tour: Wind Energy
Monday 9 September 2019 at 14:00-16:30

Boat tour to Middelgrunden Offshore Wind Farm with participation from Middelgrunden Wind Turbine Cooperative
The Middelgrunden Offshore Wind Farm is one of the first offshore wind farms in the world. It has a total capacity of 40 MW and consists of 20 Bonus turbines each with a power of 2 MW. Middelgrunden Offshore Wind Farm provides 3 per cent of the electricity consumption in Copenhagen.

Ten of the wind turbines are owned by the energy company HOFOR and the remaining ten belong to Middelgrunden Wind Turbine Cooperative. This means that a number of Copenhagen citizens own a share of the turbines. More than 90% of all offshore wind turbines worldwide come from Danish companies. Offshore wind power requires specialised expertise, and Danish companies have vast experience in meeting the challenges of constructing offshore wind power plants.

Time and venue
14:00 Departure from Nyhavn Hotel, Nyhavn 71, 1051 Copenhagen. The boat departs from this harbour and returns to the same place.

Price
60 EUR including boat trip, guided visit and coffee/tea.

Registration
Registration at https://smartenergysystems.eu/registration/ before 31 August 2019.
Registration is binding. Limited number of seats.

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5TH INTERNATIONAL CONFERENCE ON

Smart Energy Systems

4th Generation District Heating, Electrification, Electrofuels and Energy Efficiency

10-11 SEPT 2019 • COPENHAGEN

AALBORG UNIVERSITY DENMARK

PROGRAMME

Tuesday 10 September 2019

#SESAAU2019

08:00-09:00	Registration and breakfast	Lobby 1st floor
09:00-11:00	**1st plenary session chaired by Professor Poul Alberg Østergaard**	Mermaid /Citadel 1st floor
09:00	Opening speech by Professor Henrik Lund	
09:15	Plenary keynote by Professor Jianjun Xia: District Energy Systems in China	
09:40	Plenary keynote by Kristian Ruby, Secretary General: Dispatches from the European energy transition	
10:05	Plenary keynote by David Connolly, PhD, CEO: Wind power and district energy in Ireland	
10:30	Questions and discussion	
10:45-11:15	Coffee break	Lobby 1st floor

Parallel sessions 1-6

11:15-13:00 LOUNGE 1, 2nd	11:15-13:00 CITADEL 1, 1st	11:15-13:00 LOUNGE 2, 2nd	11:15-13:00 CITADEL 2, 1st	11:15-13:00 MERMAID, 1st	11:15-13:00 HARBOUR, 1st
Session 1: Smart Energy Systems analyses, tools and methodologies	Session 2: Smart Energy Systems analyses, tools and methodologies	Session 3: Integrated energy systems and smart grids	Session 4: GIS for energy systems, heat planning and DH	Session 5: Energy Lab Nordhavn	Session 6: 4GDH concepts, future DH production and systems
Chair: Paula Ferreira	Chair: Reinhard Haas	Chair: David Connolly	Chair: Steffen Nielsen	Chair: Svend Svendsen	Chair: Henrik Madsen
Session keynote: Dagnija Blumberga	Session keynote: Pierrick Haurant	Session keynote: Ralf-Roman Schmidt	Session keynote: Bernd Möller	Session keynote: Jan Eric Thorsen	Session keynote: Ingo Weidlich
Amir Mohammad J. Khoshbaf Borna Doračić Carles Ribas Tugores Ingo Leusbrock Carlo Winterscheid	Bernhard Gerardts Jes Donneborg Arthur Clerjon Michael-Allan Millar Mariagrazia Dotoli	Behnam Zakeri Akos Revesz Mathieu Vallée Edward O'Dwyer Jens Brage	Eva Wiechers Hermann Edtmayer Marcus Hummel Magda Kowalska Mostafa Fallahnejad	Christine Emilie Sandersen Hanmin Cai Henrik Pieper Kevin Michael Smith Morten Herget Christensen	Annelies Vandermeulen Jens Møller Andersen Janette Webb Helge Averfalk Anna Volkova

13:00-14:00	Lunch	Lobby 1st floor

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PROGRAMME Tuesday 10 September 2019 (continued)

Parallel sessions 7-12	**14:00-15:45 LOUNGE 1, 2nd** **Session 7: Production, technologies and electrofuels in future energy systems** **Chair: Iva Ridjan Skov** **Session keynote: Mads Friis Jensen** Steffen Nielsen Alessandro Guzzini Andrei David Benedetto Nastasi Jesper Schramm	**14:00-15:45 CITADEL 1, 1st** **Session 8: Smart Energy Systems analyses, tools and methodologies** **Chair: Ralf-Roman Schmidt** **Session keynote: Gorm Bruun Andresen** Egbert-Jan van Dijck Rowan Molony Kun Zhu Kristoffer Steen Andersen Roberto Bricalli	**14:00-15:45 LOUNGE 2, 2nd** **Session 9: Planning and organisational challenges for SES and DH** **Chair: Frede Hvelplund** **Session keynote: Bent Ole Gram Mortensen** Christian Thommessen Paolo Leoni Richard van Leeuwen Zhikun Wang Michiel Fremouw	**14:00-15:45 CITADEL 2, 1st** **Session 10: Smart Energy Systems analyses, tools and methodologies** **Chair: Peter Sorknæs** **Session keynote: Paula Ferreira** Géremi Gilson Dranka Rasmus Elbæk Hedegaard Sara Månsson Shahrooz Abghari Weronika Radziszewska	**14:00-15:45 MERMAID, 1st** **Session 11: 4GDH concepts, future DH production and systems** **Chair: Peter Jorsal** **Session keynote: Sara Kralmark** Steen G. Olesen Klaus G. Lauridsen Dennis Kerkhof Klara Ottosson David Edsbäcker	**14:00-15:45 HARBOUR, 1st** **Session 12: RES and waste heat sources for district heating** **Chair: Morten Abildgaard** **Session keynote: Goran Krajačić** Hiroyasu Shirato Shalika Walker Allan Oliveira Friederike Stelter Julio Vaillant Rebollar
15:45-16:15	**Coffee break**					
Parallel sessions 13-18	**16:15-17:45 LOUNGE 1, 2nd** **Session 13: Institutional and organisational change for SES** **Chair: Bent O.G. Mortensen** **Session keynote: Alessandro Provaggi** Ari Laitala Kirsten Hasberg Max Fette Renee Heller	**16:15-17:45 CITADEL 1, 1st** **Session 14: Smart Energy infrastructure and storage options** **Chair: Anders Dyrelund** **Session keynote: Reinhard Haas** Michael Reisenbichler Keith O'Donovan Tiziano Gallo Cassarino Joseph Maria Jebamalai	**16:15-17:45 LOUNGE 2, 2nd** **Session 15: Electrification of transport, heating and industry** **Chair: Jesper Schramm** **Session keynote: Tobias Fleiter** Amela Ajanovic Eliana Lozano Timo Kannengiesser Elisa Guelpa	**16:15-17:45 CITADEL 2, 1st** **Session 16: Smart Energy Systems analyses, tools and methodologies** **Chair: Søren Djørup** **Session keynote: Peter Sorknæs** Raffaele De Iulio Els van der Roest Costanza Saletti Matteo Giacomo Prina	**16:15-17:45 MERMAID, 1st** **Session 17: 4GDH concepts, future DH production and systems** **Chair: Richard van Leeuwen** **Session keynote: Henrik Madsen** Igor Krupenski Phil Jones Sabine Jansen Tobias Sommer	**16:15-17:45 HARBOUR, 1st** **Session 18: Smart Energy Systems analyses, tools and methodologies** **Chair: Gorm Bruun Andresen** **Session keynote: Brian Elmegaard** Francesco Neirotti Jann Launer Ashish Chawla Tom Prinzie
17:45-19:30	**Break**					
19:30	**Conference dinner Restaurant "GRØFTEN", Tivoli**					

5TH INTERNATIONAL CONFERENCE ON

Smart Energy Systems

4th Generation District Heating, Electrification, Electrofuels and Energy Efficiency

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TENTATIVE PROGRAMME

Wednesday 11 September 2019

#SESAAU2019

Parallel sessions 19-24	**9:00-10:45 LOUNGE 1, 2nd** **Session 19: Smart Energy Systems analyses, tools and methodologies** **Chair: Jakob Z. Thellufsen** **Session keynote: Philipp Schütz** Hagen Braas Martin Heine Kristensen Michele Tunzi Pierre J.C. Vogler-Finck Andra Blumberga	**9:00-10:45 CITADEL 1, 1st** **Session 20: 4GDH concepts, future DH production and systems** **Chair: Jan Eric Thorsen** **Session keynote: Alfred Heller** Basak Falay Gerald Schweiger Leire Chavarri Richard Büchele Maria Jangsten	**9:00-10:45 LOUNGE 2, 2nd** **Session 21: Integrated energy systems and smart grids** **Chair: Tom Brown** **Session keynote: Vittorio Verda** Inger-Lise Svensson Monica Arnaudo Olatz Terreros Tijs Van Oevelen Shadie Broumandi	**9:00-10:45 CITADEL 2, 1st** **Session 22: Smart Energy infrastructure and storage options** **Chair: Anton Ianakiev** **Session keynote: Anders Dyrelund** Gunnar Rohde Hans Christian Gils Sina Steinle Søren Møller Thomsen Giorgio Cucca	**9:00-10:45 MERMAID, 1st** **Session 23: 4GDH concepts, future DH production and systems** **Chair: Marie Münster** **Session keynote: Dietrich Schmidt** Hjörleifur G. Bergsteinsson Johannes Oltmanns Johan Dalgren Tobias Ramm Vilhjálmur Nielsen	**9:00-10:45 HARBOUR, 1st** **Session 24: Smart Energy Systems analyses, tools and methodologies** **Chair: Steen Schelle Jensen** **Session keynote: Morten Karstoft Rasmussen** Etienne Cuisinier Thibaut Résimont Can Tümer Ana Turk Danica Maljkovic
10:45-11:15	Coffee break					Lobby 1st floor
Parallel sessions 25-30	**11:15-13:00 LOUNGE 1, 2nd** **Session 25: Smart Energy Systems analyses, tools and methodologies** **Chair: Brian Elmegaard** **Session keynote: Henrik Dalsgaard** Stefan Holler Johannes Pelda Charlotte Marguerite Johannes Röder Saleh Mohammadi	**11:15-13:00 CITADEL 1, 1st** **Session 26: Smart Energy Systems and 4GDH concepts, production and systems** **Chair: Vittorio Verda** **Session keynote: Tom Brown** Dominik Franjo Dominković Hironao Matsubara Behzad Rismanchi Tetsunari Iida	**11:15-13:00 LOUNGE 2, 2nd** **Session 27: Smart Energy Systems analyses, tools and methodologies** **Chair: Goran Krajačić** **Session keynote: Marie Münster** Daniel Møller Sneum Sylvain Quoilin Frederik Banis Naoya Nagano Steven de Jongh	**11:15-13:00 CITADEL 2, 1st** **Session 28: UN District Energy** **Chair: Bernd Möller** **Session keynote: Morten Jordt Duedahl** Dejan Ivezić Nyamtsetseg Ivanov Romanas Savickas Susana Paardekooper Zhuolun Chen	**11:15-13:00 MERMAID, 1st** **Session 29: 4GDH concepts, future DH production and systems** **Chair: Ingo Weidlich** **Session keynote: Mei Gong** Hanne Kauko Hannes Poier Marco Cozzini René Kofler	**11:15-13:00 HARBOUR, 1st** **Session 30: Smart Energy Systems analyses, tools and methodologies** **Chair: Dagnija Blumberga** **Session keynote: Jakob Zinck Thellufsen** Ewoud Werkman Kristine Askeland Roberto Vaccaro Salman Siddiqui Isabelle Best
13:00-14:00	Lunch					Lobby 1st floor

14:00-16:30	**2nd plenary session chaired by Professor Brian Vad Mathiesen**	Mermaid /Citadel 1st floor
14:00	Plenary keynote by Poul Skjærbæk, Chief Innovation Officer: Offshore Wind Power & Electrofuels	
14:30	Plenary keynote by Jean-Michel Glachant, Director: The second wave of electricity system revolutions: Peer-2-Peer and Communities	
15:00	Plenary keynote by Søren Hermansen, CEO: Resilient communities – Samsø island - a living lab for community ownership	
15:30	Questions and discussion	
16:00	Closing session and award ceremony	

5TH INTERNATIONAL CONFERENCE ON

Smart Energy Systems

4th Generation District Heating, Electrification, Electrofuels and Energy Efficiency

10-11 SEPT 2019 • COPENHAGEN

AALBORG UNIVERSITY
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PROGRAMME

Thursday 12 September 2019

#SESAAU2019

Smart Energy System Tour: District Heating and Cooling
Thursday 12 September 2019 at 9:00-14:00

Visit to Albertslund Utility and HOFOR District Cooling

Albertslund Fjernvarme (Utility) supplies the municipality of Albertslund, a suburb to Copenhagen, with district heating. Albertslund Utility is establishing a new low-temperature district heating system. A change to 4th generation district heating, where the supply temperature is lowered from 90 to 55 °C, gives considerable advantages. The lower return temperature allows higher overall efficiency in the CHP plant and lower overall temperatures mean less heat loss from the grid. Lower operation temperatures also facilitate the connection of low-temperature heat sources, such as industrial process heat, solar and geothermal energy, both directly and via heat pumps.

HOFOR is the largest utility company in Denmark, with core business areas within water supply, wastewater management, district heating, district cooling, and gas supply. One million Danish consumers (20% of the population) depend on the supplies. Introduction to remote metering data and data usage for grid efficiency purposes and low-temperature district heating. In response to increasing demands for air conditioning and cooling in Copenhagen, HOFOR, has built a district cooling system, which consists of a distribution net and two cooling plants. The district cooling system uses seawater to cool the water supplied to consumers. HOFOR can supply the increased demand for cooling in Copenhagen and help reduce CO_2 emissions by up to 30,000 tonnes each year.

Time and venue

09:00 Pick-up at Hotel Wakeup Copenhagen, Borgergade 9, 1300 Copenhagen
14:00 Drop-off at Kastrup Airport

Price

60 EUR including bus trip, guided visits, sandwich and beverages

Registration

Registration at https://smartenergysystems.eu/registration/ before 31 August 2019.
Registration is binding. Limited number of seats.

Tuesday 10 September 2019 - Contents of sessions 1-6

Session 1: Smart Energy Systems analyses, tools and methodologies
Session keynote Dagnija Blumberga: Solar Thermal or Solar Electricity, that is the question for 4GDHC
Amir Mohammad J. Khoshbaf: Technical Feasibility Assessment of 4th Generation Solar-Assisted District Heating System in Melbourne
Borna Doračić: Analysis of the integration of heat and electricity prosumers into the existing energy system with the focus on solar technologies
Carles Ribas Tugores: Large-scale solar thermal and storage for district heating in Austria: Results of techno-economic evaluation and detailed simulation studies
Ingo Leusbrock: Lessons learnt and guidelines for large-scale solar thermal and storage applications for district heating in an Austrian context
Carlo Winterscheid: Evaluation of solar district heating opportunities in Lithuania and Bosnia and Herzegovina

Session 2: Smart Energy Systems analyses, tools and methodologies
Session keynote Pierrick Haurant: Generation of daily load typology for district heating simulation and optimisation
Bernhard Gerardts: There is no need for complexity in diversifying the district heating sector
Jes Donneborg: Replacing Coal-Fired Plants with Renewable Sources Integrated with Thermal Storage
Arthur Clerjon: Matching intermittent electricity supply and load with energy storage: An optimization based on a time scale analysis
Michael-Allan Millar: Thermal Supply Peak Shaving for Residential Housing Stock in the UK
Mariagrazia Dotoli: Energy Scheduling of a Smart District Microgrid with Shared Photovoltaic Panels and Storage: the case of the Ballen marina in Samsø

Session 3: Integrated energy systems and smart grids
Session keynote Ralf-Roman Schmidt: Blockchain Applications and Case Studies in District Energy and Power-to-Heat
Behnam Zakeri: Interconnection of Denmark and UK: A comparative cost-benefit analysis
Akos Revesz: Conceptual design of a large scale 5G district energy network in London
Mathieu Vallée: A techno-economic assessment of combined heating and cooling production plant for district thermal network
Edward O'Dwyer: Coordination of district-level smart energy systems: multi-objective considerations
Jens Brage: Demand-side management in district heating and cooling: Final overview and conclusions from the Horizon 2020 STORM project

Session 4: GIS for energy systems, heat planning and DH
Session keynote Bernd Möller: The scale of district heating based on excess and geothermal heat in Europe
Eva Wiechers: A new basis for heat sector planning in Schleswig-Holstein: development of a regional heat atlas
Hermann Edtmayer: Spatial Agent-based simulation of thermal energy transition pathways in urban environments
Marcus Hummel: Possible synergies of heat planning processes across different cases in Europe. Applying the Hotmaps Toolbox
Magda Kowalska: Application of Hotmaps toolbox in the project DeCarb Supporting the Clean Energy Transition of Coal-Intensive EU Regions
Mostafa Fallahnejad: Determining District Heating Transmission Line Routes and Costs

Session 5: Energy Lab Nordhavn
Session keynote Jan Eric Thorsen: Smart operation of ULTDH booster substation for multifamily building
Christine Emilie Sandersen: Flexsumers - smart-energy ready heat customers
Hanmin Cai: Flexibility in integrated energy system: experimental insights from EnergyLab Nordhavn project
Henrik Pieper: The integration of seasonal characteristics of heat sources and sinks in energy planning and their impact on heat pump performance and dimensioning
Kevin Michael Smith: Online MPC of a heat-booster substation for ultra-low temperature district heating
Morten Herget Christensen: Heating demand peak shaving in smart homes

Session 6: 4GDH concepts, future DH production and systems
Session keynote Ingo Weidlich: Durability of DH pipe systems exposed to thermal ageing and cyclic operational loads
Annelies Vandermeulen: Simulation-based assessment of energy flexibility offered by the thermal capacity in district heating network pipes
Jens Møller Andersen: 4-pipe District heating system
Janette Webb: Heat networks in the UK
Helge Averfalk: Heat loss comparison for single pipe, twin pipe and triple pipe configurations
Anna Volkova: Scenario development methodology for the district heating regions in Estonia

Tuesday 10 September 2019 - Contents of sessions 7-12

Session 7: Production, technologies and use of electrofuels in future energy systems
Session keynote Mads Friis Jensen: Power2liquids – Methanol as Electro fuel in efficient methanol Fuel cell vehicles
Steffen Nielsen: Assessing the geographical potential of biogas methanation in Denmark based on the existing biogas sources
Alessandro Guzzini: Analysis of the existing barriers and of the suggested solutions for the implementation of Power to Gas (P2G) in Italy
Andrei David: The potential of methanated biogas in the Danish transport sector
Benedetto Nastasi: Power-To-Gas potential for energy flexibility of grid-connected and off-grid geographical islands
Jesper Schramm: Review of ammonia as an electrofuel for Internal Combustion Engines

Session 8: Smart Energy Systems analyses, tools and methodologies
Session keynote Gorm Bruun Andresen: Impact of climate change on the most cost-effective technologies for decentralized heating in Europe
Egbert-Jan van Dijck: Effective use of Stakeholder Management Technology to stimulate system innovation: initial lessons from a multiple case study of 4DHC in NW Europe
Rowan Molony: Development of an Irish energy system model for the analysis of current Irish energy policy and possible alternatives
Kun Zhu: Go or wait? The impact of emission pathways on the European energy system transition under myopic planning
Kristoffer Steen Andersen: To EE or to VE: Interaction between VE and EE in meeting long term climate policy
Roberto Bricalli: Impact of climate change on long-term planning of electrical systems based on renewable sources in Europe

Session 9: Planning and organisational challenges for SES and DH
Session keynote Bent Ole Gram Mortensen: Purpose limitation for smart metering data
Christian Thommessen: An innovative concept to increase the efficiency of existing combined heat and power plants in developing district heating systems
Paolo Leoni: Developing innovative business models for reducing return temperatures in district heating systems: approach and first results
Richard van Leeuwen: Towards municipal heat solution strategies
Zhikun Wang: Sizing of district heating systems based on smart meter data – Understanding aggregated domestic energy demand in Great Britain
Michiel Fremouw: How LowEx can you go? Validating the PLANHEAT (D)HC toolkit at the TU Delft campus

Session 10: Smart Energy Systems analyses, tools and methodologies
Session keynote Paula Ferreira: The importance of demand response for low carbon energy scenarios
Géremi Gilson Dranka: Demand Response Potential in Brazil: Theoretical Assesment
Rasmus Elbæk Hedegaard: Investigation of the energy flexibility potential of Danish residential building archetypes
Sara Månsson: Validation of fault detection methods for district heating customer installations
Shahrooz Abghari: Data Analysis Techniques for Monitoring District Heating Substations
Weronika Radziszewska: Testing of a price-based decentralized system for power balancing on real-life HVAC installation

Session 11: 4GDH concepts, future DH production and systems
Session keynote Sara Kralmark: Introduction to COOL DH
Steen G. Olesen: How to convince the locals to change to LTDH, Østerby example
Klaus G. Lauridsen: Development of a 4th generation District Heating preinsulated piping system
Dennis Kerkhof: Xplorion - energy efficient building using low temperature district heating
Klara Ottosson: Heat driven appliances
David Edsbäcker: Securing a lower grid temperature through increased digitalization—Using heat load forecasting and feedback from the grid

Session 12: RES and waste heat sources for district heating
Session keynote Goran Krajačić: Techno-economic analysis of upgrading heating systems into sustainable DHS
Hiroyasu Shirato: Development and Application of New Heat Supplying Systems Utilizing Hot Spring Water in the Northern Island of Japan
Shalika Walker: Analyzing possibilities of using energy from surface and sewage water for the energy transition of the built environment - Study in the Netherlands
Allan Oliveira: Low-Enthalpy Geothermal Heating Systems Modeling: Reducing Risks for Decision Makers and Consumers
Friederike Stelter: Trends of hybrid energy systems with the focus on power-to-heat technologies
Julio Vaillant Rebollar: A framework for energy performance assessment of a large BREEAM certified GEOTABS implemented in Kortrijk

Tuesday 10 September 2019 - Contents of sessions 13-18

Session 13: Institutional and organisational change for SES
Session keynote Alessandro Provaggi: What are the next priorities for innovation in Europe?
Ari Laitala: Organizational challenges and possibilities for energy efficiency enhancement in the Finnish municipality sector
Kirsten Hasberg: From distribution grid to interaction grid: Fundamental questions of roles and tariffs of distribution grids in 100 % renewable energy systems
Max Fette: System friendly operation of sector coupling devices: between welfare requirements and business reality
Renee Heller: Progress towards 4DHC in different national and regional contexts

Session 14: Smart Energy infrastructure and storage options
Session keynote Reinhard Haas: On the role of storage in smart energy systems
Michael Reisenbichler: Towards large-scale thermal energy storages for renewable district heating systems
Keith O'Donovan: gigaTES: Giga Scale Pit Storage as essential part of district heating system
Tiziano Gallo Cassarino: Designing zero emission, least cost, and high renewable energy systems that optimise storage and interconnections
Joseph Maria Jebamalai: Influence of centralized and decentralized thermal energy storage on district heating network design: A comparative case study

Session 15: Electrification of transport, heating and industry
Session keynote Tobias Fleiter: Deep decarbonisation of the EU industry - A model-based assessment of alternative pathways
Amela Ajanovic: Prospects for the electrification of passenger cars
Eliana Lozano: Electro-HTL biorefinery for the production of advanced liquid biofuels
Timo Kannengiesser: Design and Evaluation of Flexible Sector-coupling Pathways in Future Urban Energy Supply Systems
Elisa Guelpa: Integration of power to heat technology in thermal networks

Session 16: Smart Energy Systems analyses, tools and methodologies
Session keynote Peter Sorknæs: Livø – A micro-scale smart energy system
Raffaele De Iulio: Analysis of Smart Energy System approach in local Alpine regions - a case study in Northern Italy
Els van der Roest: Power to X: a novel, reliable, affordable and clean energy and water system for a neighbourhood
Costanza Saletti: A smart controller for small-scale district heating and cooling networks: development and testing
Matteo Giacomo Prina: EPLANopt optimization model based on EnergyPLAN applied at regional level: the future competition on excess electricity production from renewables

Session 17: 4GDH concepts, future DH production and systems
Session keynote: Henrik Madsen: Perspective in Using Meter Data for Temperature Optimization
Igor Krupenski: Low temperature district heating network energy cascade connection to the return line of a high-temperature district heating network
Phil Jones: 5th Generation Heat Networks - A Roadmap to decarbonising heat using ultra low temperature networks
Sabine Jansen: Designing smart low temperature heat grids based on spatial allocation of demands and sources
Tobias Sommer: The reservoir low temperature network: A new topology for simultaneous heating and cooling

Session 18: Smart Energy Systems analyses, tools and methodologies
Session keynote Brian Elmegaard: Accurate modeling of heat pumps and excess heat sources in energy system models
Francesco Neirotti: Comparison of electricity mixes in generation and demand: the case of heat pumps in Alpine regions
Jann Launer: Open models of optimal system operation in central vs. decentral heat supply
Ashish Chawla: A practical approach to performing Pinch Analysis followed by Heat Exchanger Network retrofit of an oil refinery
Tom Prinzie: Floating Solar Photovoltaic System: Part 2 - Insight on the feasibility and optimal design considering ecosystem thermodynamics

Wednesday 11 September 2019 - Contents of sessions 19-24

Session 19: Smart Energy Systems analyses, tools and methodologies
Session keynote Philipp Schütz: Automated building modelling based on Smart Meter Monitoring Data
Hagen Braas: Generating DHW load profiles of buildings with realistic simultaneity for DH system simulations using DHWcalc and TRNSYS
Martin Heine Kristensen: Citywide hourly dynamic heat load forecasts using building archetype modelling
Michele Tunzi: Smart double loop network for ultra-low temperature district heating in low-heat density areas
Pierre J.C. Vogler-Finck: Data-driven control for efficient and flexible energy use at building level – field investigations in Denmark
Andra Blumberga: Smart Urban Regeneration in Transition to Positive Energy Block

Session 20: 4GDH concepts, future DH production and systems
Session keynote Alfred Heller: HEAT 4.0 – Digitally supported Smart District Heating
Basak Falay: Enabling large-scale dynamic simulations and reducing model complexity of district heating and cooling systems by aggregation
Gerald Schweiger: 4th Generation District Heating - a SWOT-AHP Analysis
Leire Chavarri: Flexible district heating network model that predicts mass flow, pressure and temperature losses
Richard Büchele: Opportunities and challenges of future district heating portfolios
Maria Jangsten: High Temperature District Cooling – Challenges and Possibilities

Session 21: Integrated energy systems and smart grids
Session keynote Vittorio Verda: Proper modelling approaches for operational simulation and optimization of large district heating networks
Inger-Lise Svensson: Reducing local energy system CO2 emissions by exploiting differences in district heating and electricity CO2 intensity in a local energy market
Monica Arnaudo: Techno-economic Assessment Of Distributed Heat Pumps Integration Within a Swedish Neighbourhood
Olatz Terreros: Pooling concepts for domestic heat suppliers in Austria
Tijs Van Oevelen: Testing and evaluation of the STORM controller in two demonstration sites
Shadie Broumandi: Residential heat consumption drivers towards 4th generation district heating: An econometric approach for Viborg district heating in Denmark

Session 22: Smart Energy infrastructure and storage options
Session keynote Anders Dyrelund: Smart integration of district heating, district cooling, waste water and ground source cooling
Gunnar Rohde: Improving Effectiveness and Efficiency of Smart Energy System using the Nerve Switch® Technology Stack
Hans Christian Gils: Integrated modelling of the future electricity and gas supply in Germany
Sina Steinle: Time dependent flexibility potential of Heat Pump Systems for Smart Energy System Operation
Søren Møller Thomsen: Smart integration of fluctuating renewable energy into the energy system
Giorgio Cucca: Co-simulation tool for hybrid energy system optimization

Session 23: 4GDH concepts, future DH production and systems
Session keynote Dietrich Schmidt: Implementation of low temperature district heating systems - Successful case studies of IEA DHC ANNEX TS2
Hjörleifur G. Bergsteinsson: Methods for Identifying Critical Temperature for Control of Low-Temperature DH Systems
Johannes Oltmanns: Decreasing the temperature of an existing district heating network
Johan Dalgren: Temperature utilization in Thermal Energy Storage and its system impact on future (4th) Generation of District Heating Systems
Tobias Ramm: Development and investigation of optimised operation strategies for district heating systems with variable temperatures
Vilhjálmur Nielsen: Preparing a school building from 1920's for low temperature district heating while improving indoor climate by use of wireless sensors

Session 24: Smart Energy Systems analyses, tools and methodologies
Session keynote Morten Karstoft Rasmussen: Data-driven decision support for optimisation of heat installations
Etienne Cuisinier: Energy system investment planning: a methodological review towards a new approach at the territorial level
Thibaut Résimont: A multi-period MILP model for the topological optimization of a district heating network
Can Tümer: Challenges in Heat Network Topology Optimization
Ana Turk: Two -stage stochastic day-ahead scheduling for integrated heat, electricity and gas system as MILP model
Danica Maljkovic: Machine learning algorithms for modelling consumption in district heating systems

Wednesday 11 September 2019 - Contents of sessions 25-30

Session 25: Smart Energy Systems analyses, tools and methodologies
Session keynote Henrik Dalsgaard: A pathway to emission free district heating in a world driven by data and electricity – Case: data center waste heat utilization
Stefan Holler: Methodology to assess the potential of waste heat from industry, service sector and sewage water
Johannes Pelda: sim4dhs – an algorithm to simulate tree and meshed district heating networks dynamically
Charlotte Marguerite: Optimization of flexible electricity loads of a buildings cluster using distributed model predictive control
Johannes Röder: Design of renewable and system-beneficial district heating systems using dynamic emission factors for grid-sourced electricity in optimization models
Saleh Mohammadi: Optimization of temperature levels in decentralized solar feed-in heat grids, A case study of Dutch refurbished building in a residential neighbourhood

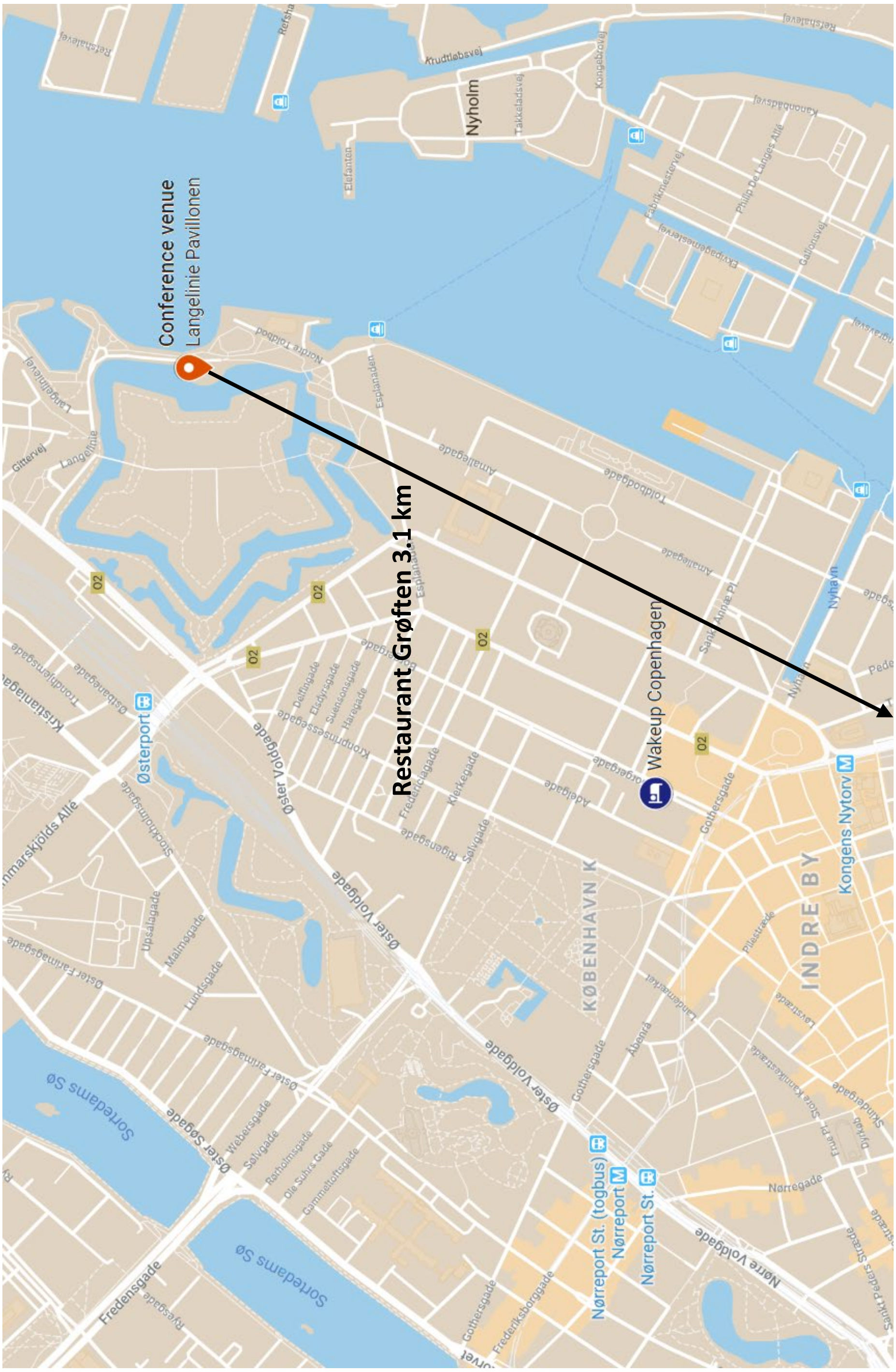
Session 26: Smart Energy Systems and 4GDH concepts, production and systems
Session keynote Tom Brown: The cost-benefit of transmission grid reinforcement in a highly-renewable European smart energy scenario
Dominik Franjo Dominković: A Potential for Interconnecting District Heating Grids: The Case of the Greater Zagreb Region
Hironao Matsubara: Current Status and Issues of Renewable Heating System towards 4DH in Japan
Behzad Rismanchi: Resilience metrics and drivers for energy system planning at the community level
Tetsunari Iida: Issues of renewable energy heat policy and establishment of 4DH forum in Japan

Session 27: Smart Energy Systems analyses, tools and methodologies
Session keynote Marie Münster: What is the benefit from sector coupling?
Daniel Møller Sneum: Evaluating barriers to flexible grid integration of district energy
Sylvain Quoilin: Modeling the flexibility offered by coupling the heating sector and the power sector: an assessment at the EU level
Frederik Banis: Handling Uncertainty in Sector Coupled Systems using Dynamic Programming and Model Predictive Control
Naoya Nagano: Introducing sector coupling to utilize renewable resources for regional decarbonization in Japan
Steven de Jongh: Machine learning based state-estimation in sector coupled energy distribution systems

Session 28: UN District Energy
Session keynote Morten Jordt Duedahl: Internal Rate of Return and how it affects development of city wide district heating projects
Dejan Ivezić: The State and Perspective of Belgrade District Heating System Development
Nyamtsetseg Ivanov: Applicability of Solar-Assisted Heat Pump System for Space Heating in Mongolia
Romanas Savickas: Challenges of Development of Green Field District Heating technologies in Latino America. Temuco city case in Chile
Susana Paardekooper: Heat Roadmap Europe: Heating typology as a basis for policy recommendations
Zhuolun Chen: Fast Decision Making Tools for District Cooling Project Development in Urban Planning Stage

Session 29: 4GDH concepts, future DH production and systems
Session keynote Mei Gong: Enhanced Biomass CHP plants for district heating systems
Hanne Kauko: Local thermal grids with waste heat utilization: low- or medium-temperature supply?
Hannes Poier: Model-based control of absorption heat pumping systems
Marco Cozzini: Techno-economic scenarios for neutral-temperature district heating and cooling networks based on decentralized heat pumps
René Kofler: Performance analysis of a heat pump system, providing district heating and cooling through gradual heating and cooling

Session 30: Smart Energy Systems analyses, tools and methodologies
Session keynote Jakob Zinck Thellufsen: Benefits to single country modelling: Comparing 14 interconnected individual country models to a single 14-country model
Ewoud Werkman: Modelling Energy Systems in an interoperable, reusable and comparable way
Kristine Askeland: The impact of geographical resolution of hydropower in energy systems modelling
Roberto Vaccaro: A computational model linking EnergyPLAN with Input-Output analysis for evaluating the economy-wide impact of the transition at regional level
Salman Siddiqui: A novel method for forecasting electricity prices in a system with renewables and large scale grid storage for use in energy system models
Isabelle Best: Systematic investigation of the building envelope's and hot water production systems' influence on the heat load profile of districts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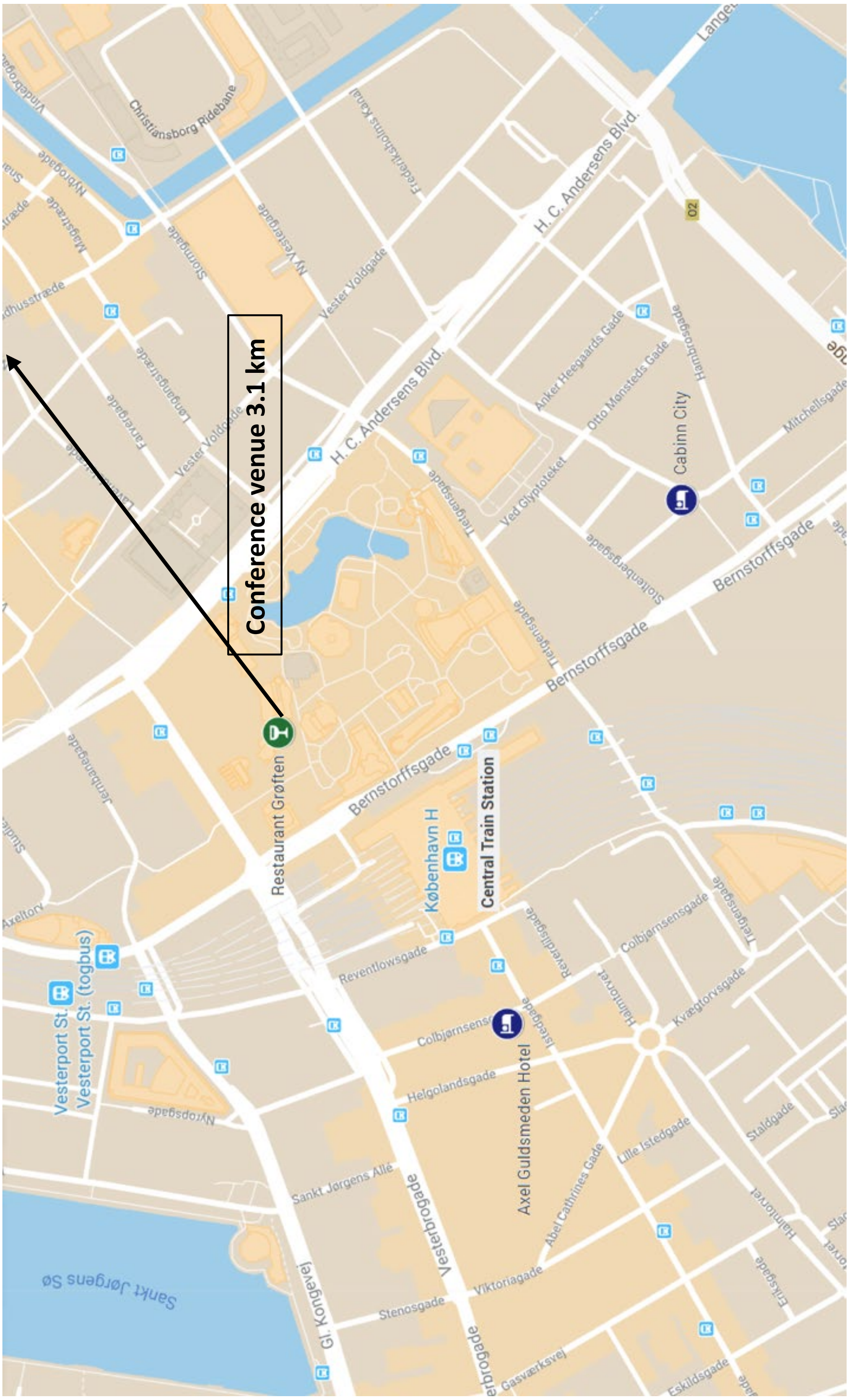

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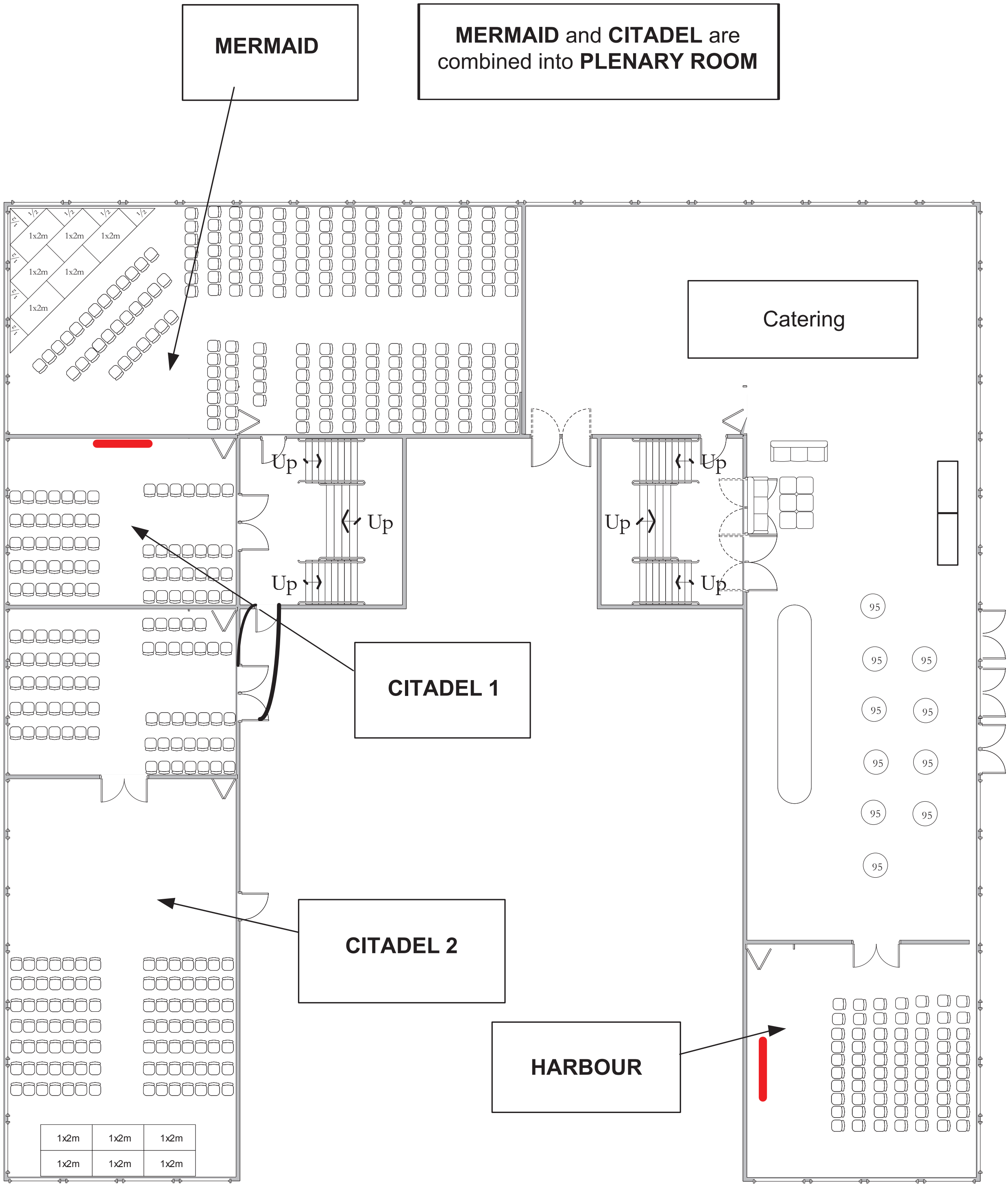

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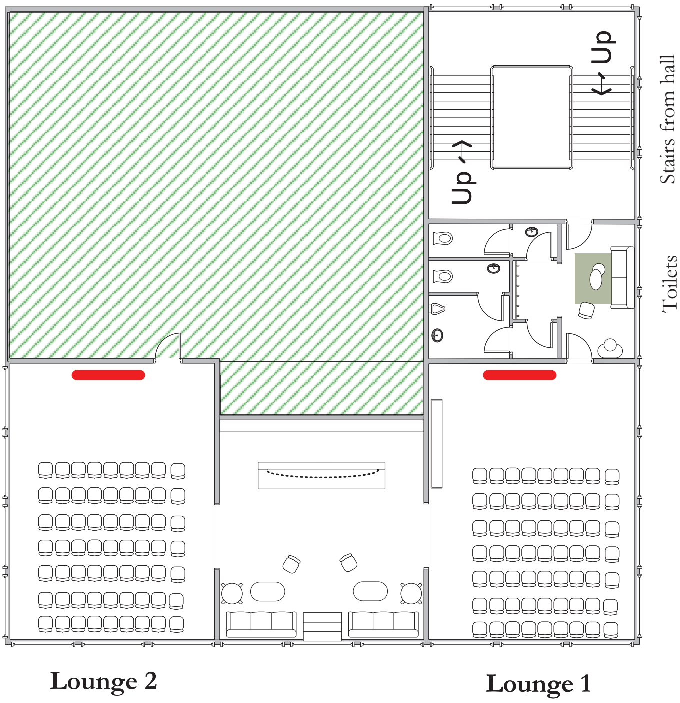

Best Senior Presentation Award is donated by Danfoss

The presentations made by senior researchers at this year's International Conference on Smart Energy Systems will all be competing for the Best Presentation Award sponsored by Danfoss. Danfoss will donate 1000 euro to the winner of the category.

At last year's conference, the winners were selected on their ability to communicate the science within their field of district heating research and thus make the subject more attractive and useful to the consumer.

Last year, Danfoss sponsored the Best PhD Presentation Award. Britta Kleinertz from the Research Center for Energy Economics won the Best Presentation Award with "Heat Dispatch Centre – Symbiosis of different heat generation units to reach cost efficient low emission heat supply".

In 2018, Britta Kleinertz from the Research Center for Energy Economics won the Best Presentation Award for PhD fellows sponsored by Danfoss. Photo: MY Fotografi v/May-Britt Vestgaard Knudsen

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The award ceremony will take place on the second conference day at 4pm in the plenary room Mermaid/Citadel 1st floor.

Last year, Kamstrup sponsored the Best Senior Presentation Award. Benedetto Nastasi from TU Delft won the award for his presentation "Synthetic fuels potential by Power-To-Gas integration at National level for enhancing energy independency".

In 2018, Benedetto Nastasi was happy to receive his award for Best Senior Presentation sponsored by Kamstrup. Photo: MY Fotografi v/May-Britt Vestgaard Knudsen

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CONFERENCE CHAIRS

Henrik Lund, Professor in Energy Planning at Aalborg University, Denmark

Professor Henrik Lund has headed several large research projects in Denmark and Europe. He holds a PhD in “Implementation of sustainable energy systems” (1990) and a senior doctoral degree in “Choice Awareness and Renewable Energy Systems” (2009). Henrik Lund has more than 30 years of research experience and involvement in Danish energy planning and policy making. Among others, he has been involved in the making of the Danish Society of Engineers’ proposal for a future 100% Renewable Energy Plan for Denmark. He has headed several large research projects in Denmark and Europe. Henrik Lund is the main developer of the advanced energy system analysis software EnergyPLAN, which has more than 1000 registered users around the world. Henrik Lund is on the Thomson Reuter’s list of highly cited researchers in the world within the topic of engineering. He has contributed to more than 400 books and articles and is Editor-in-Chief of Elsevier’s international journal ENERGY.

Brian Vad Mathiesen, Professor in Energy Planning at Aalborg University, Denmark

Brian Vad Mathiesen, Professor in Energy Planning at Aalborg University, is one of the world’s leading researchers in renewable energy systems. He is ranked among the top 1% researchers in the world in the Thomson Reuter’s list of highly cited researchers; he is Vice-Chair of the European Commission's Horizon 2020 Advisory Group for Energy (AGE) and is a member of the European Commission’s expert group on electricity inter-connection targets in the Energy Union. In his research, Brian Vad Mathiesen focuses on the technological, economic and societal shift to renewable energy, large-scale integration of fluctuating resources (e.g. wind power) and the design of 100% renewable energy systems. Brian Vad Mathiesen was one of the leading researchers behind the concepts of Smart Energy Systems and electrofuels. He has published more than 160 scientific articles and reports and is the editor and editorial board member of various international journals.

Poul Alberg Østergaard, Professor in Energy Planning at Aalborg University, Denmark

Poul Alberg Østergaard is Professor in Energy Planning at Aalborg University. He holds a PhD in “Integrated Resource Planning” (2000) and has more than 20 years of research and teaching experience within Energy Planning. Poul A. Østergaard’s research competences include analysis of energy systems with large-scale integration of fluctuating renewable energy sources; optimisation criteria of energy systems analyses, and sustainable energy scenarios for local areas. Poul A. Østergaard has led and been involved in many research projects all focusing on renewable energy scenarios, integration of renewable energy sources into the energy system and framework conditions for renewable energy scenarios. He has authored/co-authored more than 90 scientific papers in highly reputed publications and is the editor-in-chief of the International Journal of Sustainable Energy Planning and Management. Furthermore, Poul A. Østergaard is the Programme Coordinator and a distinguished teacher of the M.Sc. programme in Sustainable Energy Planning & Management at Aalborg University.

ABOUT SEENERGIES

sEEnergies is a European research project focusing on Smart Energy Systems and supply chain effects on energy efficiency in all sectors and infrastructure. The project is funded by EC Horizon 2020, Grant Agreement no. 846463. sEEnergies has a duration of 2½ years and gathers 9 partners from universities and key energy players in Europe.

sEEnergies goes beyond state-of-the-art science-based knowledge and methods, as it combines sectorial bottom-up knowledge with hour-by-hour modelling of the energy systems and spatial analysis in the EU.

The project develops a holistic temporal and spatial assessment of energy efficiency potentials by utilising energy system synergies and in this way make energy efficiency more operational as a first principle.

sEEnergies assesses the energy-related impact of the first principle of energy efficiency at the sector and energy system levels to quantify energy efficiency and make it comparable with investments on the supply side. It also assesses the additional impact of energy efficiency measures in different sectors, as well as their impact on markets in order to support policies aiming at promoting and implementing energy efficiency as a first principle.

Furthermore, sEEnergies develops an online GIS visualisation platform to make the first principle of energy efficiency more concrete in relation to energy demand and supply.

Read more about sEEnergies at www.seenergies.eu

ABOUT RE-INVEST

RE-INVEST is a four-year research project gathering 17 partners from universities and key energy players in a unique approach to the complete redesign of the entire energy system, utilizing the synergies between heat, electricity and transport.

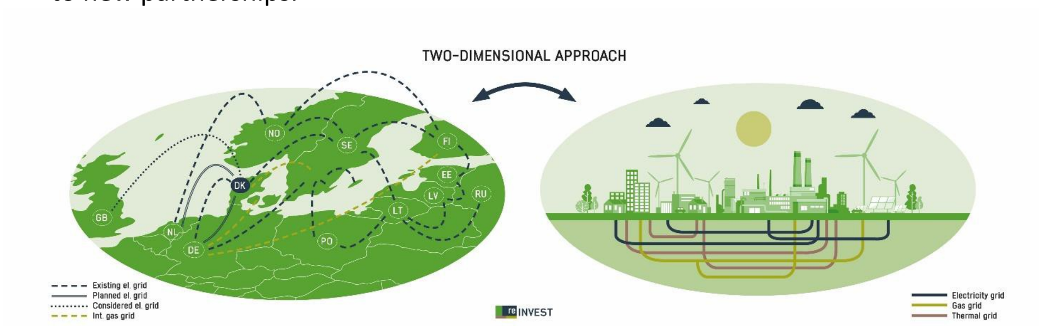
RE-INVEST aims at designing robust and cost-effective investment strategies that will facilitate an efficient transformation towards a sustainable or 100% renewable energy system in Denmark and Europe.

RE-INVEST addresses how to overcome the silo thinking that characterizes traditional energy sectors, by using a two-dimensional interconnectivity approach as well as existing and new energy infrastructures. The aims are:

1. To develop the Smart Energy System concept and identify synergies in low-cost energy storages across sectors as well as energy savings on the one side, and international electricity and gas transmission on the other side, when expanding e.g. wind power;

2. To support stakeholders within renewable energy in Denmark and Europe and enable the industrial partners in the project to be early adopters of trends in integrated energy markets, thus having cutting edge R&D for key technologies in future sustainable energy systems;

3. To share data, results, models and methodologies on open platforms and be open to new partnerships.



Read more about RE-INVEST at www.reinvestproject.eu.

PLENARY KEYNOTE SPEAKERS

Prof. **Jianjun Xia** is currently Associate Professor and Deputy Director at the Building Energy Research Center, School of Architecture, Tsinghua University. Prof. Jianjun Xia's areas of expertise include high performance HVAC equipment development, energy planning, utilization of industry waste heat for heating, and building energy systems. He is the member of the Executive Committee (ExCo) and representative for China of IEA District Heating and Cooling TCP (IEA-DHC). He is also the member of Scientific Committee of China District Heating Association. He serves as associate editor for international journal "Building Simulation". He is author or co-author of five books and more than 100 scientific papers. He is currently principle (co-) investigator for several 13th and 12th five-year national science and technology supporting projects, which involve key researchers of improving energy efficiency for district heating system in Northern China, industrial surplus heat application, and high-performance HVAC equipment.

Kristian Ruby, Secretary General of the Union of the Electricity Industry – Eurelectric, is a widely recognised expert with a strong communication profile and extensive experience in political affairs. He joined Eurelectric from Wind Europe, where he served as Chief Policy Officer and was in charge of development and implementation of the political strategy.

Prior to this, Ruby worked as a journalist and served seven years as a public servant in the Danish Ministries of Environment, and Climate and Energy and in the European Commission in the cabinet of the former Climate Action chief, Connie Hedegaard. Kristian Ruby holds a master's degree in history and international development.

David Connolly is Chairperson of the Irish District Energy Association (IrDEA), one of Ireland's newest energy associations, and CEO of the Irish Wind Energy Association (IWEA), which is Ireland's largest renewable energy association. IrDEA and IWEA work with a wide range of internal and external stakeholders to build understanding and awareness of the benefits of district energy, wind power, and the transition to a low-carbon energy system in Ireland. Previously, David served as Head of Policy in IWEA from May 2017 to March 2018, where he developed policies related to Ireland's electricity market, the electricity grid, wind farm planning, and strategic energy policy. Before that, David was an Associate Professor in Energy Planning at Aalborg University in Copenhagen where his research focused on the design and assessment of 100% renewable energy systems for electricity, heat, and transport. He graduated as a Mechanical Engineer in 2007 and completed a PhD in energy modelling in 2011, both at the University of Limerick.

Poul Skjærbæk is the Chief Innovation Officer & Senior Principal Expert in Siemens Gamesa Renewable Energy, the world's largest offshore wind power manufacturer. Poul Skaerbaek has more than 20 years of experience in the offshore wind industry, enabling early pioneering projects such as Middelgrunden, one of Denmark's first offshore wind farms, in 2000. Today, Poul heads the Offshore Innovation team in Siemens Gamesa Renewable Energy, who tests Jacket foundations, Cable-in-Pipe and several other innovations at the site of Nissum Bredning. In addition to testing new technologies, the Offshore Innovation team also investigate commercial innovation such as offshore wind power combined with Poter-to-X solutions.

Jean-Michel Glachant is the Director of the Florence School of Regulation and the Holder of the Loyola de Palacio Chair. Glachant took his PhD in economics at La Sorbonne in France. He worked in the industry and private sector before becoming professor at La Sorbonne.
He has been advisor of DG TREN, DG COMP and DG RESEARCH at the European Commission and of the French Energy Regulatory Commission (CRE). He has been coordinator and scientific advisor of several European research projects. Jean-Michel Glachant has been editor-in-chief of EEEP: Economics of Energy and Environmental Policy (an IAEE journal) and he is a current member of the Council of the International Association for Energy Economics. His research includes European energy policy (security of supply, renewable energy, energy efficiency, energy technology policy, and climate change policy), European energy internal market (design, regulation and competition policy), and Industrial organisation and market strategy of energy companies.

Søren Hermansen is the CEO and Founder of the Samsø Energy Academy, an NGO working with the consequences of climate changes, mostly focusing on green energy transition and community involvement. He has more than 20 years of experience with working with community change and sustainability development. He was the initiator and leader of the green transition of his island, Samsø, which became carbon and energy positive in seven years, between 1997 and 2005. The Energy Academy and Søren Hermansen are working towards making Samsø fossil free and circular by 2030.
Hermansen is Adjunct Professor at Aalborg University, an Honorary Doctor at the University of TU Delft, and furthermore he was given the Göteborg Award (the ‘Green Nobel Prize’) and Danish Svend Auken award.

For reasons of copyright, the following journal papers are not included in the electronic version of Book of Abstracts:

Smart energy and smart energy systems (Energy 137 (2017) pp. 556-565)
The status of 4th generation district heating: Research and results (Energy 164 (2018) pp. 147-159)

International Journal of Sustainable Energy Planning and Management Vol. 11 2016 3-14

International Journal of
Sustainable Energy Planning and Management

Energy Storage and Smart Energy Systems

Henrik Lund[1], Poul Alberg Østergaard[1], David Connolly[2], Iva Ridjan[2], Brian Vad Mathiesen[2], Frede Hvelplund[1], Jakob Zinck Thellufsen[1], Peter Sorknæs[1]

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ABSTRACT

It is often highlighted how the transition to renewable energy supply calls for significant electricity storage. However, one has to move beyond the electricity-only focus and take a holistic energy system view to identify optimal solutions for integrating renewable energy. In this paper, an integrated cross-sector approach is used to argue the most efficient and least-cost storage options for the entire renewable energy system concluding that the best storage solutions cannot be found through analyses focusing on the individual sub-sectors. Electricity storage is not the optimum solution to integrate large inflows of fluctuating renewable energy, since more efficient and cheaper options can be found by integrating the electricity sector with other parts of the energy system and by this creating a Smart Energy System. Nevertheless, this does not imply that electricity storage should be disregarded but that it will be needed for other purposes in the future.

Key words:

Smart energy systems
Energy Storage
Renewable energy
Heating
Transportation
URL:
dx.doi.org/10.5278/ijsepm.2016.11.2

Abbreviations

CAES	Compressed air energy storage
CHP	Cogeneration of heat and power
NaS	Natrium Sulphur (Sodium Sulphur) electricity storage
PHS	Pumped hydro storage

1. Introduction

The transition from a fossil fuel- to a renewable energy-based energy system is a change from utilising stored energy to tapping fluctuating energy sources that must be harvested when available, and either used instantaneously, or stored until the moment of use. Dealing with this basic condition of the ongoing system change, it is often highlighted how a transition into a 100% renewable energy supply or even less ambitious large-scale integration of renewable energy into the energy system calls for a new magnitude of energy storage. Especially within the electricity supply, a smart grid approach has focused on the need for electricity storage [1–3] in combination with flexible electricity demand and the expansion of transmission lines to neighbouring areas [4]. Sometimes it is even stated that renewable energy is not a viable option unless electricity can be stored [5]. Similarly, Locatelli et al. state *"Electrical Energy Storage Systems (ESS) are one of the*

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most suitable solutions to increase the flexibility and resilience of the electrical system"[6] and Tan et al. "point out smart [..energy storage systems] is a promising technology for [..micro grid] and smart grid applications" [7].

A key problem with much of the literature in relation to storage and renewable energy systems is their tendency to focus only on the generated fluctuating electricity and its direct storage from a smart grid approach. Even though the term smart grid can refer to different types of grids, it has for many years been associated exclusively with smart electricity grids, while other potential smart grid types, gas and thermal have been neglected. Electricity storage is and will be an important part of the renewable energy system puzzle but electricity's conversion to different storable and transportable energy carriers is crucial in order to transit to 100% renewable energy supply. The overall design of the energy system needs to be rethought as for the integration of flexible generation, different conversion technologies and grid solutions.

Therefore, in order to identify the best solutions one has to move beyond the simple smart grid approach and take a more holistic view as suggested by some authors [8–12]. Electricity storage [13], flexible electricity demand [14] and transmission capacity [15] have either limited integration capacity or are associated with higher costs or actual opposition as in the case with transmission grid expansion [16].

2. Scope, methodology and structure

This paper investigates the most efficient and least cost storage options as a part of a Smart Energy Systems Approach, as defined in [17]. By using this approach it is explained why the best storage solutions can be found by integrating the individual sub-sectors of the energy system. One of the main reasons why a cross-sector approach can identify more economically viable solutions is the cheaper and more efficient storage technologies that exist in the thermal and transport sectors, compared to the electricity sector.

The paper is written as a synthesis of the authors' previous research within the field, thus putting forward and integrating analyses and results into a comprehensive line of argument investigating first storage in different parts of the energy system, then size and cost of storage in the energy system followed by the role of thermal storage in smart energy systems. The discussion is broadened to the integration of cooling, transportation and biomass into the energy system, ending with findings on what can be accomplished at an energy systems level by utilising a smart energy systems approach with proper use of storage.

For optimal system configurations, all potential decision variables should be considered using some sort of heuristics [18], however this article focuses on the potential role of storage across the energy system as well as the benefits from integrating traditionally separate parts of the energy system – without locating specific optimal system configuration.

3. Electric, thermal, gas and liquid energy storage

This section looks in to electric, thermal, gas and liquid storage from an investment, efficiency and sizing perspective.

3.1 Cost and efficiency of energy storage options

There is a fundamental cost difference between storing electricity and storing other forms of energy. Here electricity storage is defined as a storage in which inputs and outputs are electricity even though typically electricity is converted to other forms of energy in the process.

Figure 1 shows the typical cost of electricity storage compared to thermal, gas and liquid fuel storage technologies. There is a variety of different technologies and sizes within each type of energy storage, which influences the investments and operation and maintenance costs. Even though the exact costs vary, the magnitude of these differences does not change significantly, with the costs indicating that thermal storage is 100 times cheaper in terms of investments per unit of storage capacity, compared to electricity storage. Moreover, gas and liquid fuel storage technologies are again substantially lower in investments than a thermal storage per unit of storage capacity. Note that the costs for these latter are based on underground natural gas caverns and oil tanks, however in a future renewable energy system this can also be methane or methanol produced from biomass and hydrogen from electrolysis or similar sorts of renewable energy-based fuels [19].

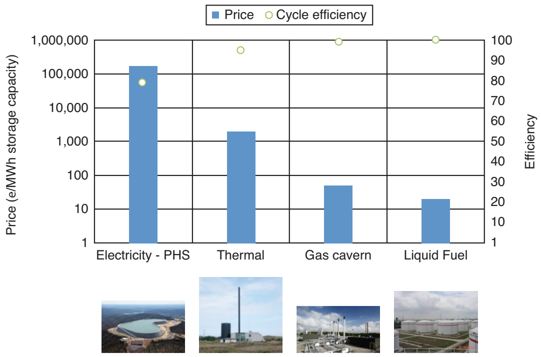

Figure 1: Investment cost and cycle efficiency comparison of electricity, thermal, gas and liquid fuel storage technologies. See assumptions, details and references in Appendix 1.

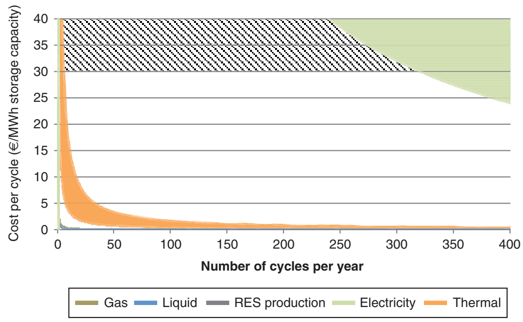

Figure 2: Annualized investment cost per use-cycle vs annual numbers of use-cycles. In the diagram the cost is also benchmarked against the cost of producing renewable energy, here shown for a wide cost span by grey (extension along horizontal axis is for presentation only; there is no cyclic dependence for renewable energy production). See assumptions, details and references in Appendix 1.

In addition to the investment issue, electricity storage is prone to significantly higher losses than any of the other types of energy storage, particularly in conversion losses. Gas caverns and oil tanks have practically nil loses; thermal storage has losses of maybe 5 percent depending heavily on size and retention time – however as electricity in almost all instances include conversion to and from the storage, losses are much more significant here.

As a consequence of investment costs and losses, the economic feasibility of electricity storage technologies depends highly on the variation in electricity prices, typically on a daily basis. However, the nature of fluctuating renewable electricity sources, such as wind power, does not typically generate such price variations. Therefore even in a system with a high share of wind power, such as the Danish case, studies show that investments in electricity storage are not feasible for the simple reason that the storage will not be used often enough to justify the relatively high initial investments [20].

Figure 2 shows how the per-use-cycle annualized investment costs of storing different forms of energy vary with the number of use cycles per year. The diagram is based on large storage technologies and shows how investment in electricity storage capacity in general requires annual cycles of at least 300-350 (equal to nearly once a day) to be able to match the cost of producing renewable energy as indicated by the hatched area. When comparing the cost of storing to the cost of producing renewable energy it should be noted that even though the electricity storage investment costs at e.g. 400 cycles per year are below the upper cost range of producing renewable energy, these storage costs include the purchasing of power to fill the storage and the operation and maintenance of the storage – nor the storage or conversion losses involved. Thus even without losses and if there is a freely available electricity source, initial investment costs in electricity storage are so high that power from the storage will only be on par with renewable electricity production if used nearly daily.

On the other hand, thermal storage investments and especially gas and liquid fuel storage are also feasible when storing energy with significantly fewer annual cycles. Here energy can be stored for weeks, months and even years due to investment costs which are even smaller. Thus, the feasibility of these other energy storage technologies is much better, especially when the energy system is rearranged to connect renewable energy to thermal, gas and/or liquid storage technologies.

Clearly, electricity storage has a more direct effect on the ability of the energy system to integrate fluctuating renewable electricity sources such as wind power [21], so a comparison cannot be made simply based on investment costs, cycle efficiencies and investment costs per cycle as shown in Figures 1 and 2. The electricity system needs to be balanced at all times but to the extent possible other storage types are more favourable as discussed as discussed later in this paper later in this paper.

3.2. Community vs individual domestic storage

Figures 3 and 4 illustrate another important factor, namely that there is a large element of economy of scale in energy storage. Figure 3 shows this point for thermal storage technologies by comparing a domestic 160 litre hot water tank with a 6000 m^3 thermal storage used by a local cogeneration of heat and power (CHP)-based district heating company [22]. Again there is a factor of 100 difference between the investments, but this time due to scale rather than type. Moreover one should note that the local CHP plant in this case has a storage capacity equal to 4 m^3 for each dwelling, whereas the maximum thermal storage installed with individual heating solutions is usually less than 1 m^3. These individual solutions are typically restricted to 1 m^3 due to the space required for the tanks. If even larger thermal storage capacity is considered, such as the seasonal thermal storage installed in recent district heating-connected solar thermal plants in Denmark[2], then the unit cost of thermal storage is reduced by an additional factor of approximately five compared to the unit cost of storage for a local CHP plant.

For the communal heat storages, this of course requires the presence of district heating systems which introduces additional heat losses in the system. In Denmark, heat losses in district heating networks vary considerably from system to system depending mainly on geographic heat demand intensity, but losses are on average approximately 20%. Efficiency improvements in the system outweigh these losses [23,24] and in the future, losses may be decreased by lowering the forward temperature of district heating grids [25].

Figure 4 illustrates how this in principle is the same for electricity storage technologies, even though the economy-of-scale influence is not as substantial as for thermal storage. In addition, for gas and liquid fuel storage technologies, there is an element of economy of scale but it is not as important since the costs of these types of energy storage are already low compared to the other costs in the energy supply. Furthermore, where charging and discharging facility costs for other types of energy storage are insignificant, these are costly for electricity storage.

The important point is that, if the renewable energy system can be designed so that it avoids electricity storage altogether and instead utilizes energy that can be stored in the form of thermal, gaseous or liquid fuels, and if this can be implemented at community level rather than in individual dwellings, then it will be more feasible to develop the storage capacity needed to integrate a high share of fluctuating electricity production such as wind, wave, and solar power.

Of course, this may come with a cost in terms of losses in energy conversion, however, these are inevitable, not only in wind or solar power integration, but in general to meet heating, cooling and transport needs in a 100% renewable energy supply [26–32]. If it is accepted that these losses are inevitable when covering heating, cooling

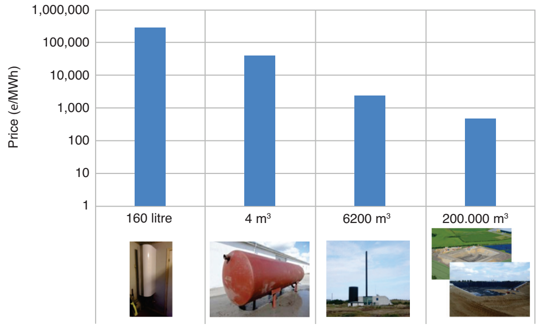

Figure 3: Investment cost comparison of different sizes of thermal energy storage technologies. The sizes correspond to storages for a dwelling, a larger building, a CHP plant and a solar DH system (see Footnote 2). See assumptions, details and references in Appendix 1.

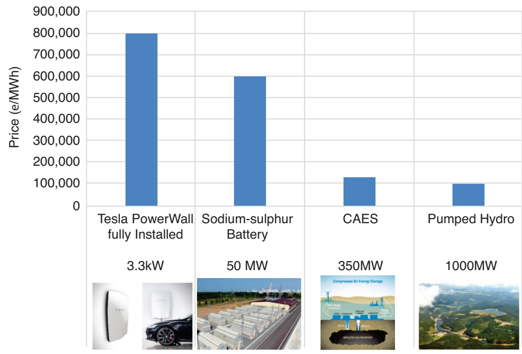

Figure 4: Investment cost comparison of different sizes of electricity energy storage technologies. See assumptions, details and references in Appendix 1.

[2] Marstal with 2306 inhabitants on the island of Ærø has two pit stores of 10,000 m^3 and 75,000 m^3 respectively [80]. Vojens (7655 inhabitants) has recently inaugurated a 203,000 m^3 pit storage [81]. Dronninglund (3328 inhabitants) has a 60,000 m^3 pit storage[82]. All population sizes from 2014 according to [83].

and transportation demands with wind and solar power, then the losses are not occurring due to the storage of the energy, but due to the conversion of energy from electricity to heat, cooling or transportation. However, in order to identify the best and the least-cost solutions, a holistic smart energy systems approach has to be adopted.

4. Smart energy systems

Smart Energy Systems may be defined as *"an approach in which smart electricity, thermal and gas grids are combined and coordinated to identify synergies between them in order to achieve an optimal solution for each individual sector as well as for the overall energy system"* [17]. Such systems encompass new technologies and infrastructures, which create new forms of flexibility, primarily in the conversion stage of the energy system. The flexibility is achieved by transforming from a simple linear approach in today's energy systems (i.e. fuel to conversion to end-use), to a more interconnected approach as shown in Figures 5 and 6. In simple terms, this means combining the electricity, thermal, and transport sectors so that the flexibility across these different areas can compensate for the lack of flexibility from renewable resources such as wind and solar.

Heat pumps in the system provides a key conversion technology between electricity and the heating sector [33–35], which combined with heat storage and the thermal mass of buildings provides flexibility for the integration of fluctuating RES-based electricity sources. Similarly, electric vehicles provides the possibility of not only a dispatchable demand but also actual electricity storage that may be fed back to the grid [36,37]. Electrofuels create a link between the electric system and transportation, so intermittent electricity production can be connected to large-scale fuel storage. Additionally, the production cycle generates heat for the heating sector thus integrating across three traditionally separate sectors.

Note that Figure 6 does not fully portray the complexity of smart energy systems to the fullest extent possible as the smart energy system is about integrating all sectors of the energy system and exploiting synergies across these.

The following sections probe further into heating, cooling and transportation, and options for adding flexibility to the smart energy system.

4.1. Smart heating and cooling

Although it is widely accepted that the heat demand will be reduced in the future, the steps of going all the way to eliminating the need for space heating is both technically challenging and very costly, especially as the heat demand nears zero. Therefore an essential question in the design of holistic least-cost solutions in the heating sector is to identify to which extent energy should be saved and to which extent renewable energy should be supplied as well as to which extent individual solutions should be used and to which extent communal systems like district heating should be used. In this context, not only do heat savings need to be implemented in the future, it is also important to consider how the heat supply should be provided for buildings.

Many recent research and demonstration projects have also focused on the concept of a zero energy buildings [38,39], however in order to reach these objectives one

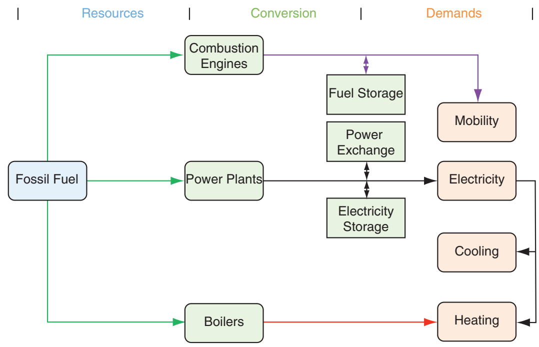

Figure 5: Today's energy systems characterised by linear paths from fuel to energy demands

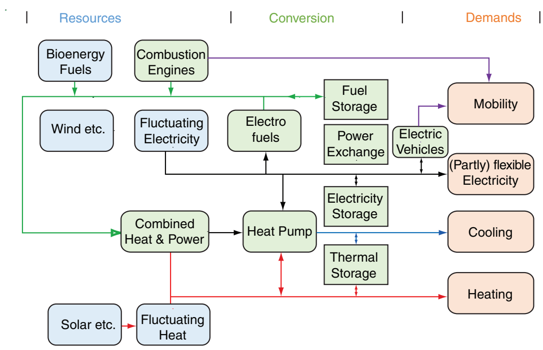

Figure 6: The integrated smart energy systems

has to include building-integrated energy supply, typically solar thermal and photo voltaic. The best solution will not be found if one considers these supplies as a part of the building; the least-cost design can only be found from a holistic smart energy approach [40].

The integration of the heating and cooling sector with electricity enables a higher fuel efficiency and increasing the share of fluctuating resources resulting in more efficient system and least-cost solutions. This becomes of even higher importance as the share of fluctuating electricity is increased towards 100% renewable energy systems.

Studies for several individual countries in Europe [41] as well as the study Heat Roadmap Europe [23,42] at the European Union level, have reached the conclusion that the least-cost way to supply heating is to combine heat savings with district heating in urban areas and individual heat pumps in rural areas. These studies also indicate that an optimal solution is to be found if savings are implemented to the level of decreasing current average heating demands by approximately 50%, although the exact number differs a bit from country to country.

The reason for applying district heating in the urban areas is that it enables obtaining the benefits of using waste heat from electricity production (CHP) and industrial waste heat [43]. Studies show that in the current system in Europe, the waste heat from electricity generation and industry is almost the same as the total heat demand of Europe [23]. As a result, by using district heating, Europe could replace half of its heating demand with waste heat and thereby save a similar share of the natural gas and oil which is currently consumed in domestic boilers.

In the future as more and more wind and similar sources replace fossil-fuel based electricity production, parts of the waste heat will come from other sources such as industry, biomass conversion and electrolysis. Moreover some heat will come from waste incineration, geothermal and large-scale solar thermal plants. However studies illustrate how the integration of wind and other fluctuating renewable electricity sources using large-scale heat pumps and thermal storage will play an important role [35,44].

The important conclusion is that power-to-heat will form an important part of the heating sector in a future renewable energy system. This applies to individual heat pumps in houses outside urban areas as well as heat pumps in district heating networks in urban areas. Similar conclusions have been made with regard to cooling [45].

One might say, that power-to-heat technology combined with dedicated heat storage or the thermal mass of buildings provide a virtual electricity storage; it can be charged when there is a high availability of renewable electricity and while it cannot be discharged back onto the grid, loads can be deferred when there is a low availability of renewable electricity.

This means that to a large extent there is the option to store renewable electricity as thermal energy at a low cost rather than at a relatively high cost in dedicated electricity storage. It will not involve any further conversion losses other than the inevitable ones that have to be accepted in any case to provide for our heating and cooling needs in the least-cost way. Furthermore, this also provides the option of increasing the integration of renewable electricity such as wind by investing in additional heat pump capacity - or to some extent also in less efficient but cheaper electric boiler capacity.

4.2. Smart biomass and transportation

In order to satisfy our transport needs in a future 100% renewable energy system with restricted biomass resources due to their high demand for various purposes [46–48], different power-to- transport options will play an important role [49,50]. In fact, electrification of the transport sector will form one of the most viable ways of ensuring balance between production and demand in the electricity system [51]. However not all transport demands can be satisfied by direct use of electricity and parts of the sector such as long-distance transportation, marine and aviation will continue to rely on gaseous and/or liquid fuel that will have be produced from available renewable energy resources. In order to solve this challenge creating an additional link between the electricity sector and transport is needed. Electrofuels [52] can store electricity in the form of liquid or gaseous fuels and hereby create flexibility in the system while meeting the demands of heavy-duty transport. In the process, fluctuating electricity is converted into hydrogen by the use of electrolysis and subsequently the hydrogen reacts with a carbon source from biomass (biogas or synthetic gas) or even from CO_2 emissions [53] to produce methane, methanol or other preferable fuels.

This enables renewable electricity storage as a gas or liquid fuel, which represents a relatively low-cost option in comparison to complex electricity storage and at the same time it provides the option of increasing the integration of wind or other fluctuating resources by investing in additional electrolysis capacity [19]. As with heating, the intention is not to supply back to the grid, but to create a deferrable load, and the conversion losses are inevitable as the energy demands for transportation needs to be meet using renewable energy sources either way.

Nastasi and Basso go as far as stating *"The Power-To-Gas option by Renewable Hydrogen production could solve the dispatch issues related to a wide deployment of RES storage devices and their priority on the energy market"*[54]

4.3. The overall system

Studies of complete regional, national or European energy transitions following the principles of a smart energy systems approach have demonstrated that it is possible to design 100% renewable energy systems where production and demand of renewable energy is balanced not only on a yearly basis but also on an hourly basis [28,30,55]. Such high-temporal resolution energy systems analyses have been conducted using the EnergyPLAN model [56,57] taking into account all types of energy (electricity, heating, cooling, electrofuels and other renewable energy fuels), conversion technologies between the sectors and hourly balance has been established using thermal, gaseous and liquid fuel storage.

A smart energy systems approach is also required to ensure the economic viability of future renewable energy-based energy systems. As noted in [58], wind power has the tendency to drive down spot market prices of electricity, thus undermining the very feasibility of wind power. Photo voltaics have the same effect, though the current implementation is not comparable to that of wind power in Denmark yet. A smart energy system with many deferrable loads across heating, cooling and transportation will thus increase the value of fluctuating renewable power generation.

5. Conclusion

The issue of energy storage is essential when discussing how to implement the large-scale integration of renewable energy both into the current system and in a future transition to a 100% renewable energy supply. A sub-sector electricity-only focus - as has been seen from a smart grid approach - typically leads to proposals primarily focused on electricity storage technologies in combination with flexible electricity demands and transmission lines to neighbouring countries. However, this paper argues that this will lead to the most expensive form of energy storage, electricity storage, which is approximately 100 times more expensive than thermal storage and even more expensive than storage for gases and liquids. It is therefore a cheaper and also a more efficient solution to utilise thermal and fuel storage technologies to integrate more fluctuating renewable energy, such as wind and solar power, than to rely on electricity storage. This however, requires a strong integration across traditionally separate energy sectors.

Thus, this paper has indicated how this cross-sector smart energy systems approach can lead to the identification of better and much cheaper options in terms of thermal, gas and liquid fuel storage in combination with cross-sector energy conversion technologies. Heat pumps, which can be in each building in the rural areas or in district heating system in the urban areas, can connect the electricity sector to thermal storage, while electric vehicles and electrofuels can connect the electricity sector to storage in the transport sector. Using these more efficient and cheaper options, it is unlikely that the other options in the electricity sector will be required solely for the integration of renewable energy. In fact, studies show that large electricity storage capacity is not economically viable for this sole purpose within any of the steps between now and a future 100% renewable energy supply.

In conclusion, for the large-scale integration of fluctuating renewable electricity sources, electricity storage should be avoided to the extent possibleis and other storage types provide an option for system balancing and flexibility while having lower costs. Direct electricity storage may be needed for other reasons but should not be prioritized if the aim is to put the electricity back to the grid.

Acknowledgements

The work presented here has been supported by 4DH – an international research centre that develops 4th generation district heating technologies and systems (www.4dh.dk) with the support of the Danish Council for Strategic Research, grant number 11-116797.

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Appendix 1: Assumptions for Figures

All data shown in Figures 1-4 are shown in Tables 1 and 2 below along with references for the data. Columns 3-6 in Table 1 are only relevant for Figure 2 and the technologies included there.

Comment on annual costs
All annual costs are calculated as an annuity of the investment based on a discount rate of 3 percent per year and the given lifetime plus fixed annual operation and maintenance (O&M) costs.

Comments on electrical storage
NaS storage is based on a ratio between installed discharge capacity and storage capacity of 6h in line with [60, 67].

Compressed Air Energy Storage (CAES) is based on a 360 MW / 1478 MWh plant.

PHS costs vary considerably from site to site. A German plant is priced at about 100,000 €/MWh [68], Electric Power research Institute lists a range from 4,40,000 to 6,00,000 US$/MWh or 3,30,000-4,60,000 €/MWh [60] at the average exchange rate of 0.755 US$/€ in 2010 [69]. As with NaS, this is based on a ratio between installed discharge capacity and storage capacity of 6h. It should be noted that PHS is by far the most used grid-connected electricity storage technology with 153 GW out of 154 GW globally [70]. Only two CAES plants are in operation – albeit both in the >100MW size range [70]. NaS experienced a ten-fold increased from on 2,000 to 2,006 thus a technology with significant development [70].

Efficiencies given in [71] for PHS are 70-80%, [60] list cycle efficiencies as 80-82% and [72] list efficiencies from 76 to 85% depending on design.

Comments on thermal storage
All thermal storages are calculated based on a ΔT=60K corresponding to a specific contents of 70 kWh/m^3. The Danish Energy Agency[71] list specific contents for large steel storage tanks and seasonal pit storages as 60-80 kWh/m^3.

The 6200 m^3 tank is an actual storage of Skagen district heating company in Denmark. The Danish Energy Agency lists costs for large steel tanks for district heating at 160-260€/m^3 [71] corresponding to 2,300-3,700 €/ MWh.

Costs of the 160 litre and the 4 m^3 tanks are based on actual bids from a supplier including installation costs. The Danish Energy Agency lists small tanks (150-500 l) at around 4€/ l - though this cost does not include installation costs [71]. This corresponds to 57,000€/MWh

Comment on gas storage
The costs are based on a gas cavern. For comparison, a five-cavern plant in Denmark with 5*100 million Nm^3 - equivalent to a total of 5.5 TWh - costs 254 M€ or 46€/MWh [71]

Comment on fuel storage
Storage costs vary according to local conditions including e.g. size and number of tanks, potential jetty construction, tank foundation details based on soil conditions. Based on actual tanks of Oiltanking Copenhagen, prices are in the 200-250 €/m^3 range.

Comment on production costs for renewable energy

As noted by [73], "cost projections [of wind, solar] are abundant [..] although with high uncertainties attached". Investigating data from the Danish Energy Authority and the Danish transmission system operator Energinet.dk on renewable energy technologies reveals a wide span of technology costs and thus production costs. The same technology costs are included from a 2012 assessment and a 2016 assessment to show how price expectations have changed with decreasing costs from on-shore wind - but increasing costs off-shore. Photo voltaics on the other hand have experienced a significant decrease over the same period of time.

For comparison, median scenarios for biomass prices in Denmark show costs of 6.2 €/GJ in 2015 and 7.1 €/GJ in 2030 [74] CIF[3] Danish harbour - giving a marginal fuel cost of 50-57€/MWh for a biomass condensing power plant with an efficiency of 45%. Coal - with a September 2016 price of approximately 72 US$/t [75] (64€/t) - has a fuel cost of approximately 18€/MWh based on a condensing mode power plant with an efficiency of 45%. Average CIF prices for industry in Denmark in 2015 were 382 DKK/t [76] or 50€/t - thus a fuel cost of electricity of 14€/MWh if coal prices for power plant are equal to coal prices for industrial coal users.

In Figure 6, renewable electricity production is shown as a band from 30 to 50 €/MWh.

[3] Cost, insurance and freight.

Table 1: Characteristics for storage technologies.

Storage type	Investment cost [€/MWh storage capapcity]	Fixed O&M [% of investment]	Lifetime [Years]	Annual costs [€/MWh storage capacity]	Cycle efficiency
Electricity – PHS [59]	175000	0.5	50	4387	0.80
Electricity – NaS [60]	600000	0.5	30	33612	0.85
Electricity – CAES [20]	125000	–	–	–	–
Electricity – Tesla [61]	660000	–	–	–	–
Thermal – pit [62]	500	0.5	30	28.0	0.85
Thermal – large tank [63]	2500	0.5	25	156	0.95
Thermal – 4000 l [64]	24000	–	–	–	–
Thermal – 160 l [64]	180000	–	–	–	–
Gas [65]	60	0.5	50	2.6	0.98
Liquid [66]	20	0.5	30	1.1	1.00

Table 2: Wind and photo voltaic technology costs and production assumptions. Total production costs are calculated based on the other columns (and are thus not calculated by the stated references). Investment costs are calculated as an annuity using a discount rate of 3 percent. Years (2015 and 2030) refer to prognoses for the two years.

	Investment cost [€/MW]	Technical lifetime [Years]	Capacity factor	Fixed O&M [€/MW]	Variable O&M [€/MWh]	Total production cost [€/MWh]	Total production cost [DKK/MWh]	Source
Wind – Large on-shore 2015	1400000	20	0.337	n.a.	14	40	298	[77]
Wind – Large on-shore 2030	1290000	20	0.365	n.a.	12	34	254	[77]
Wind – Large off-shore 2015	3100000	20	0.457	n.a.	19	61	457	[77]
Wind – Large off-shore 2030	2300000	25	0.502	n.a.	16	49	366	[77]
Grid-connected PV 2015	2000000	30	0.091	n.a.	34	216	1620	[77]
Wind – Large on-shore 2015	1070000	25	0.37	25600	2.8	31	236	[78]
Wind – Large on-shore 2030	910000	30	0.38	22300	2.3	29	217	[78]
Wind – Large off-shore 2015	3500000	25	0.5	72600	5.5	72	542	[78]
Wind – Large off-shore 2030	2700000	30	0.53	55000	3.9	58	436	[78]
Large grid-connected PV 2015	1200000	30	0.122	12000	0	93	697	[79]
Large grid-connected PV 2030	820000	40	0.140	8160	0	72	539	[79]

Plenary keynote

Jianjun Xia
Tsinghua University, China

District Energy Systems in China - Options for Optimization and Diversification

China has many reasons to pursue a more sustainable energy future. Energy resource scarcity and security are likely to be major incentives in coming decades to curtail energy demand growth. Air quality is another key influence on China's increasing commitment to restrict inefficient and polluting fossil fuel combustion, along with government policies to limit carbon dioxide (CO2) and other greenhouse gas (GHG) emissions. The lecture will present the current situation of China district energy systems and analyses the ways to decarbonise, optimise and diversify district energy systems in the Chinese context. It includes survey on the different type of renewable energy resources, demand side renovation, long distance distribution network, and high efficient integration of the heat, electricity and gas infrastructures within the design of the future energy systems.

Plenary keynote

Kristian Ruby
Secretary General of the Union of the Electricity Industry – Eurelectric

Dispatches from the European energy transition

In Europe, a new political cycle is about to begin. After five years with major overhauls of emission trading, renewable and efficiency targets, power market design and emission standards for cars, the new generation of policy makers is expected to continue and deepen the thrust towards zero-carbon society. What are the implications for the energy system, what are the triggers and barriers to success?

Plenary keynote

David Connolly
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Wind power and district energy in Ireland

Wind energy is the most successful renewable energy technology developed in Ireland to date, accounting for 29% of electricity in 2018. According to data from the Irish Wind Energy Association (IWEA), wind energy in Ireland began to develop at pace in the early 2000s and since then Ireland has become a world leader in the sector, proving that with clear policy and a stable regulatory framework, radical technological change towards sustainable energy is possible. In contrast, Ireland has struggled to develop large volumes of renewable heat over the same period, with one of the key reasons often cited being the lack of district energy networks. Ireland has a climate, population density, and energy system which are all suitable for district energy to deliver sustainable and cost-effective heating in its urban areas, but there is currently a major shortage of knowledge, capacity, standards, and policy in Ireland to facilitate the implementation of large-scale district energy networks. The Irish District Energy Association (IrDEA) was set up in 2017 to overcome these barriers, by informing key stakeholders in Ireland about all aspects of district energy. This talk will compare and contrast these two pivotal technologies, wind power and district energy, as both will required in Ireland's future Smart Energy System. In particular, some of the learnings from the wind sector will be presented to show how they are now being applied to create a new district energy industry, which include: 1) identifying and connecting key stakeholders, 2) the development of an All-Island heat atlas 3) initiating pilot projects to demonstrate how district heating could work in an Irish context and 4) creating a voice for district heating in Irish energy policy. Already, there is evidence that these early initiatives are increasing awareness about how district heating among decision-makers in the Irish energy sector, particularly in the context of a future low-carbon Smart Energy System.

Dagnija Blumberga is director of Institute of Energy Systems and Environment in Riga Technical University. She has more than 20 monographies 200 scientific publications in SCOPUS and Web of Science data base in AER and energy efficiency policy and bioeconomy research fields.

Solar Thermal or Solar Electricity, that is the question for 4GDHC

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The implementation of low temperature DH systems the needs to be embedded in an overall energy strategy, which investigates and displays the possibilities on how to apply such a system. There is no single solution for all DH systems how to lower the heat carrier temperature, integrate solar energy and raise the overall operational efficiency. Hence, it requires a careful strategic planning process toward the sustainable development of new generation type DH system. For all these reasons this methodology aims to present the steps for a detailed analyses of existing DH system, future heat consumption forecasting in order to select of most suitable transformation pathways towards a more efficient heat supply by use of solar energy as a heat and/or power source. In the following parts the approach is described as a cyclical process implemented in several consequential steps. Figure 1 reports the conceptual scheme of the proposed methodology to better implement transformation strategies to move towards LTSDH implementation. The methodology includes three mathematical methods: regression analysis, multicriteria analysis and system dynamics modelling. Solar energy integration in 4GDH system has a high potential in the future, because its implementation is closely related to building energy performance. With the development of low-consumption buildings, DH companies will be interested to lower the heat transfer temperature in order to reduce the specific transmission costs.

Keywords: solar electricity, solar thermal, 4GDH systems, system dynamics model, multicriteria analysis

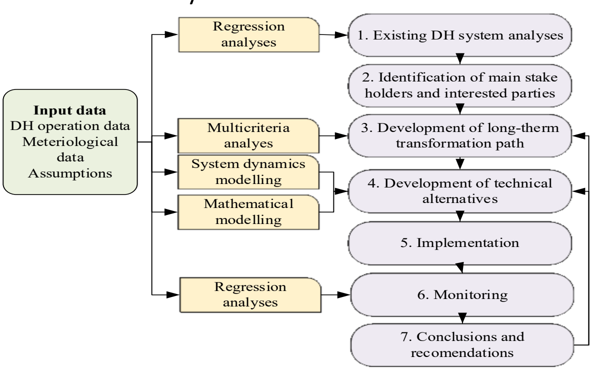

Figure 1: Overview of proposed methodology and used methods

Amir Mohammad Jodeiri is a student of European Master in Renewable Energy from Hanze UAS (Netherlands) with specialization in solar thermal (University of Perpignan, France). He is currently finalizing his master thesis on "solar-assisted district heating systems" at CSIRO Energy Centre, Australia.

Technical Feasibility Assessment of 4th Generation Solar-Assisted District Heating System in Melbourne

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Low temperature district heating is a potential solution to lower primary energy consumption and make better use of renewable energy sources for building space heating (SH) and hot water services. District heating (DH) systems are common in Europe, while it is relatively unknown in Australia despite the fact that there is a significant winter heating demand in some cities. The current research presents a feasibility study of a DH system that uses low-temperature water to enable integration of solar energy in Melbourne, Australia. A site with 1,000 residential units housing a population of 3,000 people was considered. The annual primary energy use of domestic hot water (DHW) systems with and without integration of solar energy was compared with that of conventional individual DHW system. TRNSYS modelling and parametric analysis were used to explore the effects of linear heat density, R-value of insulation material, seasonal storage capacity and solar field size on energy performance of DH systems. In addition, the impact of using some of the heat to meet winter SH demand was investigated. Results suggest that an optimally-designed DH system without solar energy integration is unlikely to be competitive compared to individual domestic systems in Melbourne due to the relatively high annual energy losses (20%). However, integrating a 7,500-m2 solar field and a 30,000-m3 hot water tank can save up to 97% and 25% of the primary energy use in the DHW and SH systems respectively.

Keywords: Solar district heating system, feasibility study, primary energy saving, TRNSYS, optimization, seasonal heat storage

Borna Doračić has been working at University of Zagreb since 2016 as a research assistant and a PhD candidate. His work mostly focuses on energy planning of different systems, with the focus on excess heat utilization in district heating as a part of future smart energy systems.

Analysis of the integration of heat and electricity prosumers into the existing energy system with the focus on solar technologies

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Prosumer has an increasing role in the energy transition where bi-directional flow of energy and information will be achieved with the utilization of smart grids in the newly built energy systems. The main goal of the energy transition is to eliminate the use of fossil fuels and shift towards the renewable energy sources where distributed energy production will be the best response to the increasing energy demand. Even though the concept is already rather well known, the examples are lacking, especially for the east and south-east European countries. Hence, the aim of this research was to analyze the technical and economic possibilities of the prosumer integration in the energy systems of today, with the focus on the south-east Europe. The analysis was performed for the Lanište neighborhood in the city of Zagreb, Croatia. The focus was on the integration of solar technologies at the consumer side, to produce both electricity and heat. The system was modelled in the energyPRO software and the optimization of the operation was performed, in order to define the amount of excess electricity production which is sold to the network. Heating demand was covered by the own production from solar thermal collectors, while the remaining demand was covered by district heating. The share of self-consumption, the feed in and feed out of the network have been calculated. Finally, the environmental impact of prosumer integration was also analyzed with the focus on CO2 emissions.

Keywords: prosumers; distributed energy generation; solar thermal; photovoltaic

Carles Ribas Tugores is working in the field of simulation of district heating systems and the techno-economic evaluation of sustainable supply concepts for district heating systems.

Large-scale solar thermal and storage for district heating in Austria: Results of techno-economic evaluation and detailed simulation studies

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District heating in dense urban environments possesses significant CO2-reduction potential as DH allows for integration of renewable energies, storage technologies and waste heat utilization, substituting fossil fuels and increasing flexibility of the energy system increases. Here, the combination of large solar thermal plants with long term thermal storages (with or without heat pumps) is becoming a widely accepted option, especially in Denmark. Nevertheless, this concept cannot be directly included in every DH system. It needs to be adapted to the local boundary conditions and, most important, be aimed to solve the specific challenges of the energy system under study. This paper presents the work carried out in the Austrian project Urban-DH-extended project which focus on the increase of flexibility and share of renewables in Austrian district heating systems. The specific situation regarding flexibility issues and share of renewables is analyzed for three different cities and different energy concepts based on the successful Danish energy concepts are proposed. The results of a two-step approach – techno-economic feasibility study and detail simulations - are presented on base of the investigated DH systems. Feasibility studies focus on preliminary sizing of the components based on a technical and economic evaluation by means of simplified calculations. Detail simulations are used for more detailed evaluation with control strategies and dynamics as a central part.

Keywords: Storage, solar thermal, techno-economic feasibility, detailed simulation

Ingo Leusbrock is leader of the research group "On-Grid Energy Supply and System Analysis" at AEE INTEC and focusses on development, planning and simulation innovative energy supply concepts.

Lessons learnt and guidelines for large-scale solar thermal and storage applications for district heating in an Austrian context

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District heating in dense urban environments possesses significant CO2-reduction potential as DH allows for integration of renewable energies, storage technologies and waste heat utilization, substituting fossil fuels and increasing flexibility of the energy system increases. Here, the combination of large solar thermal plants with long term thermal storages (with or without heat pumps) is becoming a widely accepted option, especially in Denmark. Nevertheless, this concept cannot be directly included in every DH system. It needs to be adapted to the local boundary conditions and, most important, be aimed to solve the specific challenges of the energy system under study. The paper presents the lessons learnt in the Austrian project Urban-DH-extended, which focusses on the implementation of large-scale solar thermal and storage in combination with heat pumps in Austrian district heating systems. We will showcase the challenges for these concepts in an Austrian context and highlight the potential. We will present guidelines for integration of these concepts including recommendations for dimensioning of individual components and operational aspects. Furthermore, we will give an estimation of the potential of these concepts in Austria and Central European context and highlight remaining technical and economic challenges.

Keywords: storage, best practice, solar thermal, guidelines

Carlo Winterscheid

Evaluation of solar district heating opportunities in Lithuania and Bosnia and Herzegovina

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In central European countries, solar district heating (SDH) has already found wide application. In Lithuania and Bosnia and Herzegovina this is not yet the case, even though the technology can help to tackle different challenges. Within the EU H2020 project UpgradeDH, which focuses on improving the efficiency of district heating systems, different improvement measures for demo cases in eight countries are currently under evaluation. In this paper, the general status of SDH applications is shown, with an in-depth elaboration of the different opportunities and challenges for the application in Lithuania and Bosnia and Herzegovina. For the case of Lithuania, the economic risk of varying prices in biomass can be lowered through the integration of centralized solar thermal collector arrays, which offer reliable heat prices due to the discounting of the investment costs. In Bosnia and Herzegovina by contrast, air pollution in towns due to burning of coal can be reduced by the introduction of large-scale solar thermal energy in branches of the network, as the networks are usually shut down during the summer period.

Keywords: District Heating; Solar District Heating; H2020; Solar thermal;

Pierrick HAURANT is Associate Professor at IMT-Atlantique, Nantes, France. He has a background in energy and thermal engeeniering, and his research and teaching focuses on energy systems and networks.

Generation of daily load typology for district heating simulation and optimisation

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Optimization of district heating system is computationally cost intensive as it requires an important number of simulations for such complex systems, at each time steps, over long periods of time. This issue is a bottleneck clearly identified in the literature. A solution consists in simulating the system with several short time series, representative/typical of the whole period analyzed. In this paper, a method is proposed to define a typology of some inputs for DH modeling and optimization. The methodology is based on the daily demands of the DH substations characterized by aggregated key parameters which quantify the load and its variability. A k-means based clustering is done where k is determined by implementing a multicriteria decision aiding (MCDA) algorithm. At this stage, the criteria used are the intra and inter- clusters distances and the similarity of the demands in a same cluster. To generate typical days a compromise between all these criteria needs to be done. The impact of this choice on the accuracy of simulations using time series archetypes is assessed. This methodology is tested on a part of Nantes' district heating in France. It is shown the accuracy of simulations drops when the number of clusters is too low, whereas the computational time growths with the number of clusters. The comparison with real data confirms the usefulness of combining the clustering method with MCDA to detect the best compromise between computational time and accuracy.

Keywords: Heat consumption, typology, clustering, multicriteria aiding, simulations

Since 2010 **Bernhard Gerardts** has worked for SOLID in the r&d department leading national and international projects. He can lay claim to expertise in the fields of data analytics and transition of energy system.

There is no need for complexity in diversifying the district heating sector

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At present, European district heating networks use more than 80% fossil fuels and therefor are heavily affected by fluctuating fuel prices. The crucial question is "What is the best combination of locally available energy technologies to serve the demand?". Taking local constraints and wishes as well as needs of district heating companies into account, the answer implies high complexity. This complexity is understood as one of the main challenges in restructuring this sector towards renewable energy sources. We present an optimization approach, based on mixed integer linear programming (MILP), to find the best suited solution in terms of minimal CO2 emissions, minimal economic cost or a combination thereof. Cross-sectoral technologies are taken into account as well as technology cost functions that include capital, operation, maintenance and insurance costs. This MILP-based optimization approach is well known in planning of smart grids in the electrical energy sector. We now have adapted the method to the challenges and technologies of the thermal energy sector to allow application of this approach also in this sector. The evaluation of the results is ongoing, including seasonal heat storages. District heating companies get an opportunity to easily compare various technology combinations as well as to find the optimum solution in energy supply for their specific needs. Thus, the aforementioned complexity issued is resolved by proper use of sound mathematical tools.

Keywords: energy transition; optimisation-based investment desicion; solarthermal, seasonal heat storage; absorption heat pump

Jes Donneborg

Replacing Coal-Fired Plants with Renewable Sources Integrated with Thermal Storage

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After a significant increase in the CO2 allowances within the European Union (EU), the prices of CO2 emissions have continued to rise dramatically. One way to explain this increase is that coal-fired plants must have shorter lifetimes than estimated. As a result, replacing or phasing out coal-fired plants has become focus. In Denmark, achieving the country's renewable energy goals for 2035 is highly dependent on choosing those energy solutions considered most green (i.e. solar, wind and/or biomass). According to the Danish Renewable Outlook 2019, storage plays an essential role in moving towards a greener and more sustainable future. The outlook presents three scenarios for the expansion of renewable energy within the electricity sector. When it comes to integrating storage, the black scenario is listed as an impossible scenario, However, Aalborg CSP is of a different conviction. From an economical perspective, a complete replacement of coal-fired plants might not be the best option, whereas from an environmental perspective, CO2 emissions levels are non-negotiable. There must be a way to balance the economic and environmental impacts. The role of the coal-fired plants must be changed. Instead of covering base-load, the plants must instead act as back-up systems. This can be achieved by integrating renewable sources and thermal storage with the coal-fired plants. This idea is to accelerate the energy transition from coal through increasingly shifting the role of coal.

Keywords: Coal-Fired, Integrated System, Green Energy System, Thermal Energy, Thermal Storage.

Arthur Clerjon is a PhD student at CEA Liten, France. His work aims to model the French energy system to understand how to deal with large scale deployment of Variable Renewable Energy Sources. He especially focuses on the complementarity between electricity and heat storages.

Matching intermittent electricity supply and load with energy storage: An optimization based on a time scale analysis.

Arthur Clerjon (presenter), Fabien Perdu
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The rising share of Variable Renewable Energy Sources in the electricity generation mix leads to strong constraints on the whole energy system. It especially raises technological issues to handle variability and to match electricity load with supply at all times. This study introduces a new methodology to quantify the relevance of different electricity storage technologies, based on a time scale analysis. First, through signal analysis, we characterize and quantify the intermittency of photovoltaic, wind power and load time series at different time scales: from hours to seasonal variability. Then, each electricity storage technology is assessed separately from an Energy Return on Investment standpoint. Figure 1 shows the potential of each technology at each characteristic time scale. This analysis [1] was extended to understand further the global behavior of an electricity storage fleet. A linear programming approach is employed to account for the combination of different storage technologies and time scales. We eventually point out that there is, to our knowledge, no existing electricity storage technology suitable to handle monthly to seasonal intermittency. We highlight the complementarity of electricity with thermal storage and dispatchable electricity at long time scales. [1] A. Clerjon & F. Perdu, "Matching intermittency and electricity storage characteristics through time scale analysis: an energy return on investment comparison", EES. DOI:10.1039/c8ee01940a

Keywords: Energy storage, Heat, Time scale, Variability, Flexibility, EROI, Optimization, Linear Programming, Photovoltaic, Wind power, Battery, Power to gas, Compressed air, Pumped hydroelectricity storage

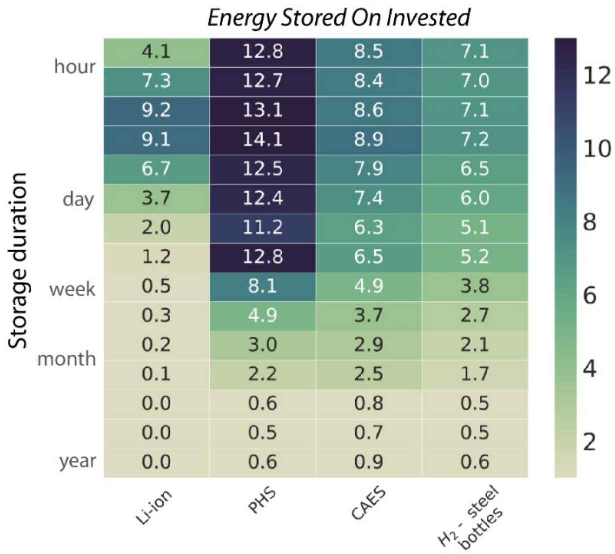

Figure 1: Field of relevance of electricity storage devices, based on an Energy Return On Investment (EROI) standpoint. The electricity generation mix considered includes 10 % PV, 27 % wind power. The higher the value, the more relevant it is to use the technology at a given time scale. .Li-ion : Lithium ion batteries. PHS: Pumped Hydro-electricity Storage. CAES: Compressed Air Electricity Storage. H_2: Power to H_2 to Power. Hydrogen is stored in steel bottles.

Michael-Allan Millar graduated from the University of Strathclyde with a joint master's in chemistry and chemical engineering. He is now a PhD student and works on the optimisation and integration of renewable technology at the University of Glasgow.

Thermal Supply Peak Shaving for Residential Housing Stock in the UK

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Residential heating in the UK accounts for over 60% of the country's domestic energy usage; this is almost entirely met by natural gas combustion, leaving a huge potential to decarbonise the heating sector. The UK has an extensive gas network – a low cost, reliable, and responsive heat delivery system that consumers can easily understand and trust. This makes it very difficult for renewable sources to penetrate the market, which are untried and have a poor track record in the UK – particularly district heating schemes. District heating is also moving towards 4th generation systems, with lower operating temperatures and a wider mix of low-grade heat integration. These systems open questions around operation, carbon saving, and optimisation previously answered for 3rd generation district heating systems. Although district heating has been shown to offer an increase in energy efficiency, a lower carbon footprint and, in some cases, lower operating costs, these schemes are rarely found in the UK. From a technical perspective, this is partially due to both the response time of the network and the lack of end user control. These issues can be addressed through the implementation of thermal storage, another technology seldom found in the UK. This study presents a technical and practical analysis of thermal storage in 4th generation district heating for residential property in the UK. This is presented as a Transient System Simulation Tool (TRNSYS) model, which considers a spread of end users (large, medium, and small residential housing) with thermal storage of different scale (subsurface/borehole storage, pit storage, and small tank storage). The model is used to predict the required volume for either seasonal or diurnal storage for peak shaving, as well as the carbon savings compared with traditional heating and 3rd generation district heating schemes. The chosen heating supply technologies are: river source heat pump, sewage heat pump and biomass boilers. First, typical housing is modelled for tenement, cottage flat and detached housing in TRNS3d, a 3D modelling software, then imported to TRNBuild to incorporate the thermal properties of the buildings. By using the TRNSYS simulation studio, the thermal supply can be compared and storage size optimised. This is provided as the first steps to develop a tool for thermal storage and operating temperature decision making.

Keywords: Thermal Storage, district heating, residential housing, UK

Mariagrazia Dotoli

Energy Scheduling of a Smart District Microgrid with Shared Photovoltaic Panels and Storage: the case of the Ballen marina in Samsø

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This contribution focuses on the energy scheduling of a smart district where a microgrid is equipped with controllable (with flexible and programmable operation) and non-controllable (with fixed power profile) electrical appliances, heat pumps, photovoltaic (PV) panels, and a battery energy storage system (BESS). The proposed control strategy aims at a simultaneous optimal planning of controllable appliances and of the shared resources, i.e., the storage system charge/discharge and renewable energy usage. We formulate a linear programming energy scheduling algorithm to maximize the self-supply with solar energy and simultaneously minimize the daily cost of energy bought from the public grid under time-varying energy pricing. The proposed energy scheduling approach is applied for the demand side management control of the marina of Ballen, Samsø (Denmark), where a smart microgrid is currently being implemented as a demonstrator in the Horizon2020 European research project SMILE. Simulations considering the marina electric consumption (340 boat sockets, a service buildings and the Harbour Master's office), PV production (60kWp), and BESS (240kWh capacity) are carried out on one year time series with a 15 minutes resolution. Results demonstrate that the approach allows exploiting the potential of local energy renewable generation and storage to reduce the marina's energy consumption costs, while complying with the users' energy needs.

Keywords: microgrid, demand side management, renewable energy, energy storage, heat pump, district energy management

Figure 1 – Scheme of microgrid in the marina of Ballen, Samsø (Denmark).

Ralf-Roman Schmidt is a senior research engineer at AIT and is responsible for the management and development of national and international projects in the field of district heating and integrated energy systems. He holds key positions in international networks (RHC-ETIP, IEA).

Blockchain Applications and Case Studies in District Energy and Power-to-Heat

Ralf-Roman Schmidt (presenter)[1]*, Mark Stefan*[1]*, Paul Zehetbauer*[1]*, Michael Niederkofler*[2]*, Andreas Schneemann*[2]*,*
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Blockchain is mostly known for its application in cryptocurrencies such as Bitcoin. However, due to its basic properties, its use in other areas has been investigated. Blockchain is a distributed database (or technically correct: "distributed ledger") shared and synchronized across a network. It is not owned or controlled by one central authority, every participant has access to its most recent version. Within this contribution, different blockchain applications and case studies in district energy and power-to-heat are discussed and analyzed based on the Austrian project "SonnWende+". - Crowd-investments into energy infrastructures (e.g. PV panels or heat pumps) are an important alternative source of finance for new projects and business ventures since it allows the general public easier, disintermediated access and participation to investments. The blockchain is enabling a continuous flowback of the revenues as well as the participation of various investors in a transparent and secure manner. - Further on, the concept of an "energy account" will be presented, enabling the collection of digital points that can be collected and exchanged for various benefits, similar to "miles and more". This point can be earned by the user e.g. via implementing measures for supporting energy generation or efficiency. The blockchain allows free trading of points between all participants.

Keywords: Blockchain, District Heating, Power-to-Heat, crowd-investments, energy account, PV, heat pumps

Dr. **Behnam Zakeri'**s research revolves around the modeling and analysis of energy systems and markets. He investigates market mechanisms, systems integration possibilities, emerging energy technologies, and policies that enable a reliable, low-carbon energy system.

Interconnection of Denmark and UK: A comparative cost-benefit analysis

Behnam Zakeri (presenter), Brian Vad Mathiesen
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The sub-sea transmission line, Viking Link, is planned to interconnect the power systems of Denmark and UK directly by 2023. The economic profitability of the project and its impact on power prices has triggered mixed opinions among experts. Denmark is already highly interconnected to neighboring power systems with enough flexible generation capacity like Sweden and Norway, while the situation is totally opposite -- a relatively low interconnectivity. This has raised the concern that the Danish tax payers will finance a project that at best will create a corridor between UK and other power systems connected to Denmark, including Germany. The lack of comprehensive model-based studies intensifies these concerns. This paper examines the economic feasibility of the line by doing market simulations and hourly modeling of future energy scenarios in the region. Moreover, the cost and benefits of the line will be compared with other alternatives such as power to heat and storage systems to inform the current discussion on the usefulness of the line quantitatively. Furthermore, this paper tests whether or not the link will increase the share of renewable energy in Denmark and UK, which is one of the main motivations of building the link.

Keywords: market coupling, renewable energy integration, flexibility solutions, energy policy, energy security

Akos Revesz is an experienced Researcher with a demonstrated history of working in the field of sustainable energy systems. His key interests include urban energy systems, low temperature heat networks, integration of waste heat, heat pumps and renewables.

Conceptual design of a large scale 5G district energy network in London

Akos Revesz (presenter)[1], Catarina Marques[1], Gareth Davies[1], Rodrigo Matabuena[2], Phil Jones[3], Chris Dunham[4], Graeme Maidment[5]

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Provision of heating and cooling is responsible for more than one third of the UK's CO2 emissions and represents about 50% of overall energy demand. Even after major efforts to reduce energy demand in other areas such as improved insulation in buildings, in order to meet the UK's carbon emissions reduction targets, it will still be essential to decarbonise the use of electricity and gas in heating and cooling. A key element of decarbonisation will be greatly increased deployment of local energy networks, primarily in urban areas. This paper introduces the conceptual design of the UK's largest fifth generation (5G) energy network using a central London location as a case study. The proposed network will include flexible electricity supply, secondary and renewable energy sources, demand side management and energy storage. The smart electricity supply will connect and flexibly control individual assets such as heat pumps and electric vehicles in response to the intermittency of renewable energy sources. The smart energy network also includes renewable and secondary thermal sources such as waste heat from the London Underground and urban data centres. The ambient district thermal loop of the network will distribute low carbon heating and cooling to a range of end users. The results presented from the conceptual design introduced will provide understanding of the relative performance of individual technologies within a complex system using a whole system modelling approach.

Keywords: 5G, Heating, Cooling, Smart, Energy, Network

Mathieu Vallée

A techno-economic assessment of combined heating and cooling production plant for district thermal network.

Nicolas Lamaison, Robin Roure, Michaël Descamps, Mathieu Vallée (presenter), Roland Bavière,
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Electrification in the heating sector, especially based on an efficient use of power-to-heat devices, has the potential to bring new flexibility services to the electric grid. It can improve grid stability when integrating intermittent renewable sources, while producing and storing thermal energy at a competitive cost. However, the practical efficiency of such a strategy is strongly dependent on the dynamic operational control of district heating plants. In the context of the PENTAGON project, we investigate the impact of several types of dynamic operational control strategies for multi-energy district heating networks: Rule-Based Control (RBC), Model-Predictive Control (MPC) and Multi-Agent Systems (MAS). To compare these strategies, we consider a small-scale district heating network located at the National Institute for Solar Energy, France, with a production plant combining a heat pump, a gas boiler and a thermal solar field with a storage tank. A Modelica-based digital twin of this network is available for simulation, and 'live' scenarios can be run on the real system to demonstrate practical feasibility. In this study, we present simulation and experimental results related to the MPC strategy. For both simulation and 'live' experiments, the MPC strategy strongly relies on predictions, and we especially highlight the impact of prediction quality on the overall results. We also provide insight regarding the practical implementation on such strategies on a real system.

Keywords: Predictive Control, Power-to-Heat/Cold, District Heating and Cooling, MILP, Optimal Sizing, SHC-HP

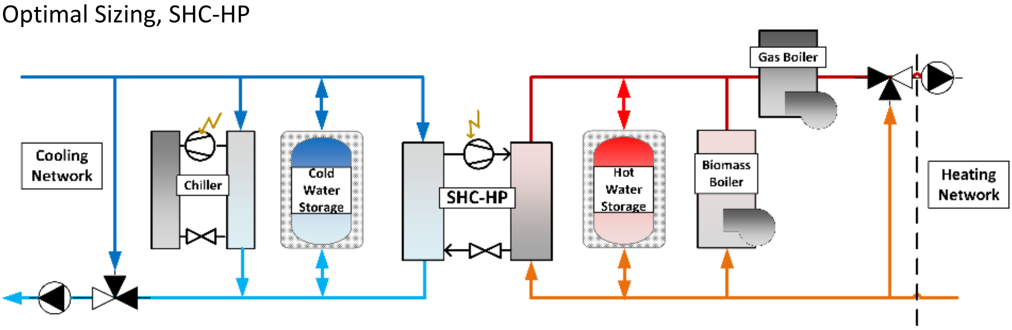

Figure 1: Studied Combined Heating and Cooling Production Plant

Edward O'Dwyer is a Research Associate in the Centre for Process Systems Engineering (CPSE) at Imperial College London. His research focusses on control, modelling and optimisation aspects of urban energy systems, with particular emphasis on the incorporation of data science and the IoT.

Coordination of district-level smart energy systems: multi-objective considerations

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The increased deployment of district heating schemes along with the electrification of heating and transport networks has introduced new opportunities for smart integration of multi-vector energy assets. With the application of appropriate coordination approaches, performance can be optimised for different criteria. Different objectives may exist, including the minimisation of operational costs or CO2 emissions, the reduction of peak loads at times of high grid stress or the maximisation of local consumption of locally generated renewable power. From a decision-makers perspective, the incorporation of such competing (and often conflicting) objectives in single framework can be a significant challenge, potentially impacting numerous stakeholders. As part of the Horizon 2020 funded Sharing Cities project, the London borough of Greenwich is carrying out a range of smart energy interventions including the installation of a centralised water source heat pump to supply heat to social housing units as well as the installation of PV panels. An energy management system has been developed to coordinate the different assets in the neighbourhood using Model Predictive Control (MPC) and optimisation-based scheduling. To design and analyse the energy management strategies a simulation environment has been developed and validated using measured data. In this setting, multi-objective problems in smart energy systems are explored in terms of environmental, financial and system resilience.

Keywords: Smart energy management, multi-objective optimisation, model predictive control, district-level energy networks, smart heating, renewable generation

Jens Brage has a PhD in Mathematics and long experience in the field of Computer science and Software development. In 2016 he joined NODA where he now works as Head of Research and Innovation. Before he joined NODA, Jens has been working with various projects ranging from measuring algorithms for high-tech manufacturing in an international setting to billing systems in the Telecom industry. He also has experience teaching mathematics and statistics at a University level.

Demand-side management in district heating and cooling: Final overview and conclusions from the Horizon 2020 STORM project

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The Horizon 2020 project STORM has spearheaded European innovation in active demand-side management for district heating during the last four years. The STORM controller is a framework for forecasting, optimising and dispatching control signals throughout a district heating system. Based on recent advancements in digitalisation, cost-efficient communication and computational solutions, it is now possible to develop and deploy such smart controllers in full-scale industrial settings. In this paper we present a final overview of the project achievements, including a discussion on a go-to-market strategy and an analysis of the financial benefits. Furthermore, the paper provides an overview of the algorithms and software architecture used in developing the controller and discusses the practical deployment in the two project demonstrations sites as well as commercial spin-off implementations. The paper focuses on the challenges that were encountered, as well as lessons learned. The results of the project are used as a basis to elaborate on the strategic value of this type of grid-level controllers for future-generation, low-temperature networks, as well as for upgrading current-generation, high-temperature systems. The main conclusions from the project are presented, together with an outlook towards the future.

Keywords: District heating, Demand-side management, Peak shaving, Integrated energy systems, Digitalisation

Dr. **Bernd Möller** is a Professor in Sustainable Energy Systems Management at Europa-Universität Flensburg in Germany and 10% Professor at Aalborg University, Denmark. Spatial analysis of energy systems and energy planning. Chair of the Energy & Environmental Management in Developing Countries.

The scale of district heating based on excess and geothermal heat in Europe

Bernd Möller (presenter)[1], Eva Wiechers[2], Urban Persson[3], Younes Noorollahi, Steffen Nielsen

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District heating is used at various geographical scales, where heat demand is dense, and heat sources are available at low costs. However, both dimensions may offer economies of scale through interconnection. This may reduce specific generation and distribution costs. Access to low-enthalpy excess and geothermal heat sources may facilitate the expansion at larger geographical scale, while improving end-use efficiency. The paper aims at identifying techno-economic potentials for the development of district heat clusters, where smaller and larger systems can share common supply, increasing the utilisation of excess heat and geothermal resources. The Pan-European Thermal Atlas and the findings of the Heat Roadmap Europe project are used to analyse scaled-up district heating in the European heat sector. Geothermal heat potentials and costs are mapped, and potential sources of industrial and other excess heat are quantified and located. Network allocation minimizes transmission routing, and supply of heat is balanced against the infrastructures needed. About 300 clusters of prospective and existing district heating systems are identified, for which costs of district heating distribution and transmission grids are modelled. Geothermal and excess heat sources are allocated in a least cost manner. Results identify significant potentials of low-grade heat supply to district heating. Interconnections to clusters offer a significant economy of scale.

Keywords: Pan-European Thermal Atlas, excess heat, geothermal heat, district heating, GIS

Eva Wiechers is a research assistant at Europa-Universität Flensburg in Germany and works in the field of spatial analysis of energy systems and energy planning.

A new basis for heat sector planning in Schleswig-Holstein: development of a regional heat atlas

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A regional heat atlas provides the basis for energy systems analyses examining heat supply strategies and "power to heat" potentials in a system with more than 100% renewable electricity; for instance relevant for municipal climate action plans. For a new heat atlas of Schleswig-Holstein in the North of Germany, existing maps of heat demand estimations have been compared: Pan-European Thermal Atlas heat demand maps, Hotmaps heat demand densities, and so far unpublished heat demand distributions for Schleswig-Holstein or parts of it, as well as local heat consumption estimations. The methodology developed for the Pan-European Thermal Atlas (Peta) relies on available datasets and does not require extensive data collection. Based on geostatistics, built up areas are mapped quantitatively, and regional heat demands are distributed by means of modelled floor area densities. This approach was validated, adjusted and improved with local data, in order to suit the urban and the rural areas of Schleswig-Holstein. The result is an online atlas showing heat demand densities on hectare level for the year 2016 and additional layers like heat distribution costs and existing district heating networks. These data form the basis for advanced energy systems analyses. The main advantage is a comprehensive, comparable and applicable model of the heating sector. Accuracy is only marginally sacrificed for speed and costs of providing a valuable data foundation.

Keywords: Heat demand density, district heating, GIS, Pan-European Thermal Atlas

Hermann Edtmayer

Spatial Agent-based simulation of thermal energy transition pathways in urban environments

Hermann Edtmayer (presenter), *Franz Mauthner*[1]; *Ingo Leusbrock*[1], *Lina Stanzel*[1], *Johannes Scholz*[2]
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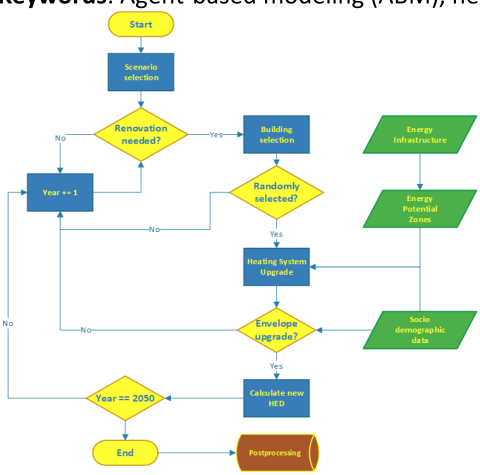
For strategic urban heat planning, analysis of the actual building stock is essential in order to identify and quantify energy demands, the refurbishment potential of buildings or the feasibility of district heating. Moreover, for future projections regarding thermal energy supply and demand not only techno-economic parameters are decisive but also socio-demographic factors that may affect the behavior of houseowners and investors in their decisions regarding building standards to apply or heating systems to install. In this respect, Agent-based Modelling (ABM) is seen to have the potential to provide insights into complex energy transition dynamics that go beyond conventional engineering methods and is especially applicable to decision-making in policy and planning. The purpose of this research hence is to describe a practical approach to generate an ABM for public policy simulation of thermal energy transition pathways in cities and communities. The method is being tested for a small city in Austria. The opensource platform GAMA is used for the spatially-explicit multi-agent modelling and simulation. In Figure 1, the rational of the proposed ABM is depicted. A more detailed description of the ABM is going to be published in Proceedings of the 2nd International Data Science Conference – iDSC2019.
Acknowledgement This research is funded by the Austrian Federal Ministry of Transport, Innovation and Technology (bmvit) and is associated with the project EnergyCityConcepts.
Keywords: Agent-based modeling (ABM), heat transition, GIS, spatial energy planning



Marcus Hummel is a senior researcher and managing director of e-think, a non-university research association located in Vienna. He works for more than 10 years in the field of energy economics and energy technology with a focus on heating and cooling. The aim is developing sound solutions for the transition towards low carbon energy systems.

Possible synergies of heat planning processes across different cases in Europe. Applying the Hotmaps Toolbox.

Lukas Kranzl, Marcus Hummel (presenter), Anders Michel Odgaard, Max Gunnar Guddat, Mostafa Fallahnejad

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Local heat planning is an important means for enhancing decarbonisation of the heat sector, in particular by preparing the ground of effective policy measures. The Hotmaps project (www.hotmaps-project.eu) develops a toolbox supporting this planning process. It is currently applied in seven pilot areas across Europe. The objective of this presentation is to identify synergies of applying the toolbox for heat planning processes in those cases. The method consists of following steps: (1) describe functionalities of the Hotmaps toolbox; (2) describe challenges and starting points of heat planning in different areas across Europe; (3) develop a reasonable sequence of Hotmaps toolbox modules for developing heating and cooling strategies in the case studies; (4) apply these modules on the case studies together with local stakeholders; (5) compare the approaches and results across the areas. As results we will provide the layout and impacts of different scenarios towards decarbonisation in several cities across Europe. In particular, the role of different measures as building renovation, district heating and local RES as well as related costs will be highlighted. Key pillars of developed heat strategies will be compared to each other Finally, we will draw conclusions regarding the possible synergies of these cases and how to replicate the application of the tool in other cities and regions.

Keywords: Heat planning and mapping, heat strategies, district heating, building renovation, scenario development, Hotmaps, Smart Energy Systems, Excess heat, renewable energy, decarbonization, GIS, open source

Magda Kowalska is a mechanical engineer and specialist energy consultant. Magda is experienced in Combined Heat and Power, Renewable Energy sources and District Heating systems. She performs techno-economic models, feasibility studies and concept design for the energy technologies and heating networks.

Application of Hotmaps toolbox in the project DeCarb Supporting the Clean Energy Transition of Coal-Intensive EU Regions

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The EU Horizon 2020 Hotmaps project is an open source GIS-toolbox and data set that supports heating and cooling planning for EU-28. The convenient interface enables the users to map and extract energy figures, e.g. heat demand, RES, industrial excess heat – to find solutions for their territories – e.g. calculate district heating potentials. The InterregEurope project DeCarb is focused on clean energy transition of the coal-intensive EU regions. Nine partners exchange experience on how to decarbonize their energy sector. The project aims to support the regions in securing sustainable development and a role in the 2030 energy mix. The outcome of DeCarb are individual action plans which will improve the policy instruments benefiting the authorities and beneficiaries. Hotmaps was utilised to determine the potential of the RES that could be used as an alternative fuel to produce low-carbon heat, cooling and electricity. The collected information facilitated a SWOT analysis which determined decarbonization growth pathways. PlanEnergi produced a manual for the regions to undertake this investigation individually. The SWOT provided an overview of the strengths and weaknesses regarding energy resources and emphasized the economic, social and environmental diversity across all EU locations. The findings increased the awareness among local authorities helping them to prioritise the adoption of alternative and diversified growth trajectories in the decarbonization of the economies.

Keywords: Hotmaps, Horizon 2020, DeCarb, Interreg Europe, Smart Energy Systems, Excess heat, district heating, coal-intensive, renewable energy, decarbonization, GIS, toolbox, open source

Mostafa Fallahnejad is an associate researcher at the EEG at TU Wien. He holds a master's degree in Power Engineering from Technical University of Munich (TUM). He joined the EEG in October 2016 and is involved in the field of energy system modelling as well as H&C planning.

Determining District Heating Transmission Line Routes and Costs

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Due to high investment and long payback time, district heating (DH) grid should be planned precisely. DH grid consists of transmission pipes with distribution pipes branching out [1]. Here, we propose a method for determination of routes, sizes and costs of DH transmission lines and apply it to the case study of Brasov, Romania. The approach will be integrated as a module in the DH-Plan model [2]. DH-Plan model maximizes the profit with respect to spatial and economical aspects of implementing district heating system. The workflow is as follows:

• Determine the primary potential DH areas using corresponding DH-Plan module.
• Calculate the medial axis (topological skeleton) of the potential DH areas and transform it to a graph.
• Use OpenStreetMap; find closest point in the streets for each edge of skeleton graph; replace them in the edge set.
• Calculate shortest path routes between sets of two edges.
• Cluster demand zones using k-means algorithm with consideration of edges as centres of clusters.
• Feed the clusters and calculated routes into the optimization module of the DH-Plan model.
• Get among all, cost optimal transmission lines' routes, costs and sizes.

Due to the consideration of the topology of DH areas and use of GIS data, the proposed method provide a good estimation of transmission lines. This method provides a generic approach. Therefore, the outputs should be regarded as pre-feasibility results that can facilitate detailed heating planning in study areas.

Keywords: District heating, GIS, optimization, infrastructure, DH-Plan model

Jan Eric Thorsen is the Director at the Danfoss Heating Segment Application Centre, which is a globally operating team of engineers acting as internal and external consultant's focusing on energy systems and conceptual development of DHC and its related systems and components.

Smart operation of ULTDH booster substation for multifamily building

Jan Eric Thorsen (presenter)[1], Marek Brand[2], Torben Schmidt Ommen[3],
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We present the smart operation of an ultra-low temperature district heating (ULTDH) consumer unit for multi-family houses with an integrated heat pump for domestic hot water preparation and domestic hot water circulation. It includes the novel installed system, field experiences related to load shift, forecast of DHW consumption and economic optimization of the operational strategy. The project is a part of the EnergyLabNordhavn project. The ULTDH Booster Substation concept opens the opportunity for load shift related to domestic hot water production. Utilising the load shift potential on the building side, can become an important part of optimising the operation of the district heating network. The DHW is produced at 55°C, DHW circulation temperature is raised continuously from 50 to 55°C, with a DH supply temperature of approximately 44°C and a DH return temperature of approximately 30°C. The share of electric energy consumption for DHW and DHW circulation is 11-19%, depending on the daily DHW consumption. The representative yearly electric share is around 14%. The electric load shift potential is in average limited to approximately 7 kWh/day, whereas the DH load shift potential is 68 kWh/day. Regarding capacity flexibility, 3 kW electric and 30 kW DH capacity is realized for a period of 1 hr. and 15 min. before the morning peak and before the evening peak, as an average over the year. The economic and predictive control is applied and successfully demonstrated.

Keywords: Heat Booster Station, Ultra Low Temperature District Heating, Load Shift, Heat Pump, 4th Generation District Heating

Christine Emilie Sandersen

Flexsumers - smart-energy ready heat customers

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Because renewable energy sources such as solar and wind are less predictable, and therefore not suitable to cover peak loads, oil and natural gas fueled boilers are started up to cover the peak loads that occur in a district heating network. However, due to the economic and environmental challenges associated with the use of fossil fuels, such as oil, the Danish Government have decided that the share of renewable energy sources in the district heating production must be increased by 33% from 9% in 2009 by the end of 2020. Thus, the production will have to cope with the penetration of renewables now, and in the future. To ensure an environmentally friendly and safe energy production for the future, part of the solution to make the district heating production in Copenhagen CO2 neutral might be to manage the heating demand at the consumer side, to allow for a more flexible energy production. A more flexible district heating consumption will make it possible to remove the CO2 emitting peak load production, and increase the share of renewables. Furthermore, the flexibility of district heating production in the future heating system, where heat pumps play an important role, could also benefit the electrical system. In the work with flexible heat consumers, also called flexsumers, the peak consumption in both residential and office buildings was relocated by reducing the heating supply for shorter periods (3-5 hours) when shorter peak loads typically occur.

Keywords: Integrated energy system, flexibility, short-term heat storage in buildings, reduction of CO2 emissions, district heating,renewable energy sources,demand side management,Energy Lab Nordhavn, LivingLab

Hanmin Cai is a PhD student from the Technical University of Denmark working on developing and demonstrating distributed energy solutions to support the flexible operation of the integrated energy system. His main interest is in the combined heat and power system.

Flexibility in integrated energy system: experimental insights from EnergyLab Nordhavn project

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As Denmark is moving towards a 100% renewable-based energy system, there has been an increasing number of intermittent renewable energy resources integrated into the electrical power system. Meanwhile, the low-temperature district heating concept envisions more distributed heat generations in the district heating system. Hence, the operators in both systems will have to adopt a flexible operation to accommodate more distributed resources. The EnergyLab Nordhavn project utilizes Copenhagen's Nordhavn as a full-scale smart city energy lab to demonstrate the integration of electricity and heating, energy-efficient buildings to support future integrated operation practice. By digitalizing both the system monitoring and the end-user devices, the project has integrated the diverse components into a uniform data management system, energydata.dk. It could not only monitor consumption and system status in real time but also enable intelligent controllers to exploit the flexibility in the systems. Flexibility is crucial to achieving overall synergy. However, the flexibility within one system is currently not visible in another system, and we lack common criteria for different systems to assess it. Moreover, the existing study and evaluation on the flexibility are mostly based on modelling and simulation and are restricted within one system. In this study, we investigate energy flexibility of integrated energy systems based on field experiments of multiple energy systems.

Keywords: integrated energy system; flexibility

Henrik Pieper is a PhD student at the Technical University of Denmark. He has recently submitted his PhD thesis. His field of research covers large-scale heat pumps, district heating and cooling, low-temperature heat sources and optimization modeling.

The integration of seasonal characteristics of heat sources and sinks in energy planning and their impact on heat pump performance and dimensioning

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We present the final results of a PhD study in which the optimal integration of heat sources and heat sinks into district heating and cooling networks has been investigated. For this, an energy planning model has been developed that considers seasonal characteristics of natural sources for the performance calculations of heat pumps and refrigeration systems. Varying source temperatures and seasonal availability, dimensioning capacities, auxiliary electricity consumption, part-load behaviour, different investment costs, short-term storage and other factors were included in the model. Thereby, performance variations of heat pumps and refrigeration systems, depending on the used heat source or heat sink, were taken into account. The optimization was based on mixed-integer linear programming. Annual calculations were performed with one hour time step. The developed planning tool was applied to a new development district, Nordhavn, in which a harbour area will gradually be transformed to a new city district of Copenhagen, Denmark. By exploiting synergies between heating and cooling demands as well as available sources and sinks, an optimal dimensioning and operation of heating and cooling equipment was identified. This led to the most efficient and economical system design as well as to a sustainable operation based on available heat sources and heat sinks. Further, it can be assessed what alternative designs may be suitable and to which additional cost.

Keywords: District heating and cooling; Energy planning; Heat pumps; Low-temperature heat sources; Optimization

Kevin Michael Smith is a Researcher at the Technical University of Denmark, where he focuses his work on model-based development and control of heating and ventilation systems for residential buildings. He completed his PhD and Master degrees at DTU and his BASc at the University of Toronto.

Online MPC of a heat-booster substation for ultra-low temperature district heating

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Ultra-low temperature district heating (ULTDH) networks rely on heat pumps to boost temperatures for preparation of domestic hot water (DHW) in a future energy system. The EnergyLab Nordhavn project tested such a system in the new Danish district of Nordhavn. The installation uses a heat pump to charge DHW tanks and includes a smaller heat pump to compensate for heat loss in the circulation pipe. The installation allows several heat sources for the smaller heat pump, including the tank bottom to improve thermal stratification. In an optimal control problem, the decision variables determine when to charge the tank and which heat source to select for the circulation heat pump. The optimal tank-charging schedule takes into account dynamic pricing of electricity and heating to enable energy flexibility. Furthermore, charging minimise return temperatures to maximise system efficiency. The authors developed an MPC implementation using validated Modelica models of the heat-booster substation. The authors validated the component and system models with data from the actual installation. The authors implemented the MPC formulation using the open-source MPCPy package, the open-source J-Modelica platform and an ARIMA model to forecast DHW tapping. The implementation provided optimal online decision variables for the actual heat-booster substation in Nordhavn.

Keywords: MPC, 4DH, district heating, Modelica, ultra-low temperature; Python, MPCPy, J-Modelica

Morten Herget Christensen

Heating demand peak shaving in smart homes

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In the heat production of district heating in Copenhagen, fossil-fueled units are used during peak-load periods, i.e. 6:00-9:00 and 17:00-20:00, in particularly cold days. In the EnergyLab Nordhavn project, experiments were conducted in 16 smart apartments to reduce peak load of district heating during its morning peak hours by shifting it to either earlier or later low demand hours. The smart apartments are equipped with KNX systems. Each KNX system is interfaced to a data management system located at PowerLabDK, DTU. There is also an integration between the KNX systems and a MQTT broker, which can be used to publish messages to the KNX buses. The apartments' heating systems consist of floor heating and the temperature setpoints can be remotely adjusted. For the experiments, the MQTT broker was used to remotely control the temperature set point of all rooms using individual reference set points. The reference set point of each room was defined individually, according to the usual internal temperature in days with no experiment running. The results from the experiment showed that the thermal inertia of the apartments was successfully used as a short-term heating storage system and peak demands were shaved efficiently without compromising occupants' thermal comfort. Therefore, the experiment proved to be a strategy that could significantly contribute to the achievement of carbon neutral district heating.

Keywords: heating demand management, field experiment, energy flexibility, smart building, carbon neutral

Ingo Weidlich has been University Professor for Infrastructural Engineering at the HafenCity University in Hamburg since 2016. He received the Dr.-Ing. degree from Leibniz University of Hanover in 2008. He is a researcher in the field of Urban Energy since 2002. https://orcid.org/0000-0003-2653-0133

Durability of DH pipe systems exposed to thermal ageing and cyclic operational loads

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Fourth Generation District Heating (4GDH) networks must be design for future energy systems, integrating renewable volatile energy sources. Herein, the lower levels of operating temperature and the greater amount of cyclic loading, could influence ageing, and the service life of 4GDH pipelines, differently from traditional DH networks, thus requiring proper analysis of the system response at the cross-sectional level.
To evaluate the material durability of 4GDH pipelines, we have analysed the behaviour of the service steel pipe, the insulation foam, and their adhesive interaction, using the analytical and experimental procedure introduced in the current IEA DHC research project 'Effects of Loads on Asset Management of the 4th Generation District Heating Networks'.
First, the accumulated steel pipe material damage is estimated through the Palmgren-Miner rule, considering temperature data collected from operating DH pipelines in Germany, Sweden, Norway, and South Korea. Then, the response of the insulation foam is investigated experimentally, through shear tests on DH supply and return pipe samples, subjected to natural and accelerated ageing under the combined effect of thermal ageing and cyclic mechanical loading.
The obtained results permit to gain a better understanding of the performance of traditional and 4GDH pipelines, that need to be suitably considered in the design standards of DH networks, contributing to a more sustainable and energy efficient infrastructure.

Keywords: fourth generation district heating system, durability of DH pipelines, foam ageing, accumulated damage, shear tests.

Annelies Vandermeulen obtained her Master of Engineering: Energy in 2016 at KU Leuven. She is currently pursuing a PhD at EnergyVille/KU Leuven on the use of control to unlock flexibility in thermal networks.

Simulation-based assessment of energy flexibility offered by the thermal capacity in district heating network pipes.

Annelies Vandermeulen (presenter)[1]; *Bram van der Heijde*[1], *Tijs Van Oevelen*[2], *Lieve Helsen*[1]
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Due to an increasing share of renewable and residual energy sources (RRES), extra measures to integrate these sources into the energy system are required. One such measure is to use the thermal capacity of district heating networks to provide thermal energy storage and, consequently, energy flexibility. By storing the heat at the right time (e.g. low energy prices, large amounts of available residual heat) and discharging at other times (e.g. high energy prices, a small amount of energy sources available), the integration of RRES can be improved. In district heating networks, there are many possibilities to store thermal energy, such as storage tanks, building thermal inertia and the water contained in the network pipes. The last option, the network pipes, entails heating the water in the network at certain times (i.e. charging the network capacity), to then decrease the temperature at other times (i.e. discharging the network capacity). However, if we wish to facilitate RRES integration through energy flexibility provided by district heating network pipes, we should investigate the potential of network pipes to offer flexibility. Hence, this study assesses which aspects are important to consider through simulation of fictional district heating networks. Among these aspects are the network characteristics (What types of networks are interesting?) and the network model (What level of detail is necessary to accurately determine the flexibility?).

Keywords: District heating, Simulation, Pipes, Energy flexibility, Thermal capacity

Jens Møller Andersen is a power plant engineer with a long experience in district heating and energy system design. Now working on modelling of integration of all kinds of energy systems by the Danish TSO Energinet.

4-pipe District heating system

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When a district heating system is a 4-pipe system it gives a higher complexity than conventional district heating systems. The 4-pipe system provides 6 different heat qualities and if the connected are prosumers, it cannot be pre defined which way the water runs in the pipes. This makes some challenges. With a 4-pipe district heating system there are 6 different qualities of heat. Traditional 2 pipe district heating system defines the amount of heat consumed or delivered by measuring flow and temperatures in and out of one prosumer by:

$$E = m * Cp * (Tin - Tout)$$

But when having a 4 pipe system and measuring in and out let flows and temperatures gives a mathematical under determined system. Therefore it cannot be judged what heat is delivers or consumed. It cannot even be defined whether heat is consumed or produced. This problem is solved with the addition of a supplementary principle: The heat is always delivered to the nearest temperature level. Therefore e.g. heat between pipe 1 and pipe 3 are settled in 2 parts, between pipe 1 and 2 and between pipe 2 and 3. When one consumer uses heat from pipe 1 to pipe 2, that return temperature will be another consumers forward temperature. Therefore a high return temperature not necessary is counterproductive. Therefore temperature levels need to be an ongoing negotiation, to fit to both producers and consumers. And the price of heat have to be adjusted for temperature, in a way that fits to the both producers and consumers.

Keywords: Accounting, temperature, prosumer, mathematical under determined

Janette Webb is Professor of Sociology, University of Edinburgh. With funding from UK Research and Innovation, she is studying European heat and energy efficiency policy & governance. She is co-director of UK Energy Research Centre and a member of the Infrastructure Commission for Scotland.

Heat networks in the UK

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District heating (DH) has a critical role to play in the future UK portfolio of low carbon heat systems. The UK Government's Clean Growth Strategy and Scottish Government's Energy Strategy both recognise this. However, at present it is challenging to develop viable business cases. Extensive gas network coverage and gas prices with tax subsidies and ineffective carbon pricing limit the types and scale of DH developments. Our research conducted an analysis to see what development approach would result in maximising the amount of heat demand connected to a network, given a particular network cost threshold. Two different models for identifying areas for development are examined – a zone density model and a cluster-density model - using zone-level heat density data from the Scottish Heat Map as exemplar. We find that the cluster-density model reaches 50% more heat demand than the zone-density model. The paper concludes by reviewing the current UK DH strategies and asks what needs to change to move to a cluster density planning model.

Keywords: low carbon heat; UK; Scotland; district heating; governance; socio-technical studies

Helge Averfalk is a PhD student at Halmstad University where he work with research questions related to low temperature district heating.

Heat loss comparison for single pipe, twin pipe and triple pipe configurations

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An integrated temperature error in current heat distribution is the temperature contamination caused by temperature degradation due to primary side recirculation between supply and return pipes at low heat demand situations. A proposed solution to this temperature error is to employ primary side recirculation, a third pipe in the distribution network to manage recirculation demands when required and thus avoid temperature contamination. Minimising the third pipe for recirculation without obtaining too high pressure head loss is the design criteria for choosing size of the third pipe. A third pipe for recirculation, two to three standard sizes smaller than the corresponding pipes have been found suitable regarding pressure head loss. Another design parameter is the heat loss from different pipe configurations, which is the focus of this study. The idea to implement a three pipe system, is to utilise a twin pipe, consisting of supply pipe and a smaller recirculation pipe, and a single pipe that constitute return pipe. The question is how heat losses with this configuration compares to either single pipe or twin pipe heat distribution? Analysis performed with COMSOL Multiphysics. Results indicate that heat losses for the three pipe configuration will be in the same order of magnitude as the single pipe heat distribution, while heat losses from twin pipe will be lower. The three pipe network configuration is one of the innovations within the EU H2020 TEMPO (768936) demonstrators.

Keywords: Low temperature, heat losses, single pipe, twin pipe, 4GDH-3P, finite element method

Anna Volkova is a senior researcher and the head of research group “Smart DH Systems and Integrated Assessment Analysis of GHG Emissions” in the Department of Energy Technology of Tallinn University of Technology, (Estonia). She defended her PHD in Riga Technical University (Latvia) in 2008.

Scenario development methodology for the district heating regions in Estonia

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It is clear that district heating(DH) networks will continue to develop and transition towards the 4th generation DH by way of reducing heat loss, increasing the share of renewable and waste heat sources. DH is of great significance for Estonia, so developing this sector is crucial for achieving Estonia’s climate and energy targets. Consumers play an important role in the transition process, which led to the development of a promotional app aimed at informing and educating consumers about DH. The app has been implemented at the national level. It is planned that one of the app modules will show consumers which energy mix will be required for DH in the future, taking into account all the planned changes and depending on the district heating region (DHR). There are 250 DHR in Estonia, and as part of this study, a general methodology has been developed for the evaluation of future DHR scenarios. Measures and goals described in Estonia’s National Development Plan of the Energy Sector until 2030 have also been taken into account, along with heating strategies available for DHRs. The methodology algorithm is based on reducing heat demand due to the increased energy efficiency of the construction sector and reduced heat loss, increased share of renewable energy, and thermal energy storage implementation, etc. The scenario shows which primary energy mix will be used to produce heat for each DHR in the future and how much CO2 will be emitted.

Keywords: energy planning, district heating regions, modelling, scenario

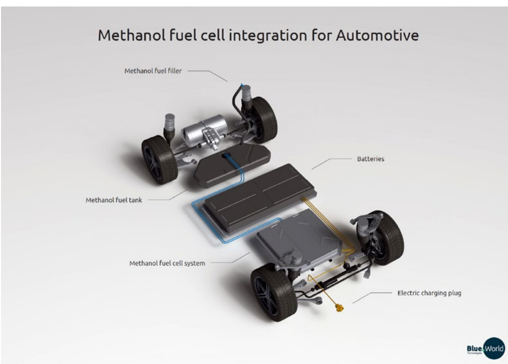
Mads Friis Jensen is a an experienced executive in the methanol fuel cell industry

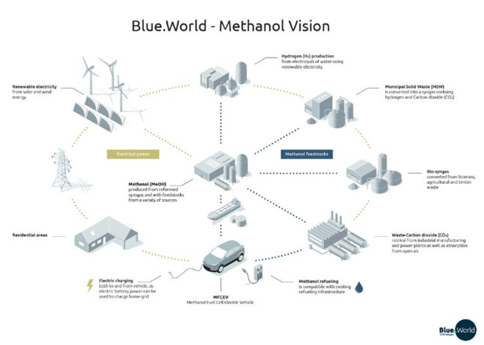
Power2liquids – Methanol as Electro fuel in efficient methanol Fuel cell vehicles

Mads Friis Jensen (presenter),
Blue World technologies

The ground transportation sector accounts for significant use of fossil fuels and particle emissions – while some of that can be solved with BEV there is a need to look beyond for many reasons. There is a need to store and distribute energy in a format that is flexible, cost effective and simple. Today this is done by liquid fuels in form of diesel or gasoline. There are two problems to solve; obtaining a liquid energy carrier from renewables and converting this into transportation work without harmful emissions and with a conversion efficiency that yields a competitive case for the user. The Methanol fuel cell can convert methanol into electricity with electrical efficiency of 40-50% while emitting zero harmful emissions. The fuel can be stored and distributed in the existing infrastructure with minor modifications. The Methanol fuel cell can be combined with a smaller battery pack in a plug-in hybrid electric vehicle offering the option for charging when feasible and Methanol range extension when needed. The battery and fuel cell can be downsized without compromising; acceleration, range, refueling method. Today green methanol has a premium cost compared to fossil methanol, however due to the simple and cost-effective infrastructure and the high electrical conversion efficiency of the methanol fuel cell today there are cost savings to be made per driven kilometer. Vehicles that are price and function comparable to conventional cars are on the way in the near future.

Keywords: Methanol, Fuel cell, HT PEM, Electro fuel, PBI, high temperature PEM, Membrane, Hybrid, RMFC, biomethanol





Steffen Nielsen works mainly within Geographic Information Systems (GIS) and Energy system analysis: Regional energy system analysis with a focus on 100% renewable energy systems.

Assessing the geographical potential of biogas methanation in Denmark based on the existing biogas sources

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Power-to-X technologies are seen as one of the key technologies in reaching 100% renewable energy targets in all energy sectors in the long term. To address the potential of using one of these technologies, this paper develops a method to assess the potential for biogas methanation plants in a larger geographic area with predefined infrastructural conditions. The focus in this paper is the availability of existing carbon sources (CO_2) from biogas producers, which are identified and localised. The analysis evaluates the location of each plant, in relation to the distance to the electricity and gas infrastructure as well as new wind potentials. The Each location is evaluated in terms of existing gas injection point and distances to district heating. The paper uses four categories to evaluate each plant: a) maximum theoretical potential without geographical constrains, b) offsite potential with distances to existing infrastructure, c) onsite potential based on existing wind turbines and d) onsite potential based on good locations for new wind turbines. The paper provides an example of applying this method in Denmark, in order to illustrate suitable locations for power-to-methane in a specific context.

Keywords: Power-to-gas, biogas, CO2, GIS, Feasibility

Alessandro Guzzini got in 2019 the Ph.D. in Mechanics and Advanced Engineering Sciences at the University of Bologna. He is a research fellow at the Department of Industrial Engineering at the University of Bologna. He has peer reviewed publications concerning safety and energy engineering topics.

Analysis of the existing barriers and of the suggested solutions for the implementation of Power to Gas (P2G) in Italy

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To reach Italian National Energy goals, new technical and economic viable solutions are required to store the surplus of energy produced by renewable plants and to make it available when required. Power to Gas (P2G) is considered as one of the best available solutions even if many questions are still unsolved. Therefore, Italian Need-Owners such as local multi-utility companies, Authorities and other energy sector stakeholders needs in detail evaluations of technical performances, systems management and of necessary strategy for hydrogen market development. In fact, because of the limited performances data and of the great number of local factors that can affect P2G plants such as for example, but not limited to, the technical performances of renewable plants and of natural gas networks, market demand. Consequently, several concerns about hydrogen production, storage and utilisation are currently present due to the lack of a method to optimize the design and the implementation of P2G plants.
For this reason, after the description of the reasons for the installation of P2G plants in Italy and of two projects at local and European levels that are going to be implemented by the Authors, the main technical, logistic, economic and regulative constraints for P2G application in Italy are identified and analysed in the first part of the paper. In the second part, possible solutions are evaluated and suggested to Italian Need-Owners to stimulate P2G implementation at national level.

Keywords: Power to Gas, Existing barriers, Implementation

Andrei David's research is centered towards the transport sector in the context of 100% renewable energy systems. He is using energy system analysis to explore the potential of electrofuels as energy storage, source of flexibility and not the least, as source of fuel.

The potential of methanated biogas in the Danish transport sector

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One of the most difficult energy sectors to decarbonise is transport due to the variety of solutions proposed, high costs, growth but also cultural choices. This paper presents one potential solution for diversifying the fuels in all types of road transport in Denmark that cannot be electrified, by exploring the potential of using methanated biogas as a transport fuel. First, the current and future feedstock availability is analysed using existing literature, followed by a review of gas vehicles and related infrastructure characteristics. The second part of the analysis simulates gradual increases in the shares of gas vehicles in the Danish road transport. The results show that the addition of gas vehicles obtained through biogas purification and methanation methods reduces the need for deploying larger shares of biomass and wind, reduces electrolyser capacity, but has a neutral impact on energy system costs compared to an energy system using the equivalent liquid fuels.

Keywords: biogas methanation, road transport, energy systems, electrofuels, P2G

Benedetto Nastasi is a Senior Researcher, MEng in Architectural Engineering, PhD in Energy Planning. His research focuses on Power-To-X applications at different scales. He is Guest Editor at Int J of Hydrogen Energy and Energies. He received the Best Senior Presenter Award at 4DH Conference 2018.

Power-To-Gas potential for energy flexibility of grid-connected and off-grid geographical islands

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Geographical islands are a challenging environment for energy transition pathways due to their physical and infrastructural features. Size and distance from the continent determine its connection to the Grid as well as the quality of supply supported by the electricity market. The Voltage level, then, if High or Medium, leads to different de facto management responsible parties entailing a primary role played by the TSO or DSO, respectively. In addition to the Business as Usual operation, when the promotion of higher renewable share and the interaction with transport sector are considered, further issues occur against a feasible and fast sustainable energy transition. Also, demand and supply depend on both weather conditions and tourism flows. Innovative business models linked to the aforementioned levels offer unique opportunity to local production, storage, production and storage leaving the stage to Virtual actors in the market. Power-To-Gas architecture appears promising as technological option for these new players. Its effects in terms of flexibility for the Power Grid when present, in terms of Demand Response for the local users and in terms of higher share of integrated renewables for the production to be eventually curtailed are analyzed in this study. Moreover, the sector coupling combined to the Power-To-Gas option shows benefits for the different aspects analyzed giving another chance to the variable electricity market to ensure a cheap and secure energy supply.

Keywords: Energy Storage; Hydrogen economy; Power to Gas; Island energy systems; Energy Flexibility; Electricity market.

Jesper Schramm is professor in combustion engines at The Technical University of Denmark. The main working field is application of alternative fuels for combustion engines.

Review of ammonia as an electrofuel for Internal Combustion Engines

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Possible sustainable ways of producing ammonia are presented and compared in an energy efficiency perspective. The role that ammonia could play as a future fuel for combustion engines in relation to the transportation sector is discussed. The engine operation relevant characteristics of ammonia are listed and discussed. An overview of issues that has to be addressed regarding the application of ammonia as a fuel for a combustion engine is given. Relevant issues are the feasible engine operation, i.e. which ignition principle, spark ignition or compression ignition, should be applied, and should the ammonia be applied with other fuels in a dual fuel concept? Other relevant issues are related to safety and emission questions.

Keywords: Ammonia, Electrofuels, IC Engines, Operation, Emissions

G.B. Andresen is Associate professor at Department of Engineering, Aarhus University. Here, he leads the research group Renewable Energy & Thermodynamics.

Impact of climate change on the most cost-effective technologies for decentralized heating in Europe

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Residential demands for space heating and hot water account for a substantial share of the total European energy demand. Of these, space heating is highly dependent on ambient climatic conditions and, thus, susceptible to climate change. We adapt a techno-economic standpoint and assess the impact of climate change on the cost optimal generation of de-centralized heating. To this end, temperature data from nine climate models implementing three Representative Concentration Pathways (RCP) from IPCC are used to estimate climate induced changes in the demand side by calculating the heat load factors at each location in Europe. The supply side is modelled by a simple approach to the economics of heat generation. We find that the demand for space heating decrease by up to 16% and 24% in low and intermediate concentrations pathways. This value reaches 42% in the most extreme global heating scenario. For the historical period, we find that countries that are dominated by cold Atlantic climate show high heat load factors. Mediterranean countries show a similar behaviour, reasoned by a high ratio between the hot water and space heat demand. In both cases, heat pumps serve as a cost optimal option of heat generation. Mainland European countries exhibit lower heat load factors for which gas boilers serve as a cost optimal choice of heat generation. Increasing ambient temperatures toward the end-century improve the economic performance of heat pumps in all concentration pathways.

Keywords: Climate change, heat generation, heating degree days, decarbonisation

Egbert-Jan is a researcher at The Amsterdam University of Applied Sciences (NL). He has earned a Master degree in Finance from Erasmus University (NL), Master degree in Leading Innovation and Change from York St. John University (UK), and Bachelor degree in Law from Leiden University (NL).

Effective use of Stakeholder Management Technology to stimulate system innovation: initial lessons from a multiple case study of 4DHC in NW Europe

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Purpose: In an attempt to enhance insight to overcome the financial, regulatory and organisational barriers preventing the development of 4DHC in NW Europe (NWE), common barriers are identified, but the issues and solutions are not well understood. Purpose is to give local authorities insight into barriers and solutions in exemplar pilot projects and the way barriers are closely linked to stakeholders in their geographical, political, and cultural context in NWE. Methods: Integrating stakeholder theory and the problem-solving perspective while leveraging action research in 6 local DHC networks in UK, Ireland, Belgium, France, and the Netherlands. Based on our Interreg HeatNet NWE research a customized multi-level stakeholder analysis framework is developed to identify stakeholders, to examine if specific barriers are interrelated to specific stakeholders, to understand the specific context, and to be able to compare the outcome of these 6 different pilot projects. Results: Initial lessons from this multiple case study of Energy Transition in NWE gives an insight into barriers and solutions and the way they closely linked to stakeholders in their geographical, political, and cultural context in NWE. Conclusion: Effective use of Stakeholder Management Technology to stimulate system innovation is a pivot between the process of in-depth understanding of user- en supply contexts and a system how to develop a stakeholder engagement plan.

Keywords: system innovation, transition research, district heating and cooling, multi-level stakeholder study

Rowan Molony is a Masters student in the School of Engineering at Trinity College Dublin. His research has focused on energy systems modelling to inform energy policy.

Development of an Irish energy system model for the analysis of current Irish energy policy and possible alternatives

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In this work, an energy system model of the current Irish energy system was developed using EnergyPLAN. Data obtained from the Irish transmission system operator (TSO) Eirgrid, the Irish grid operator ESB and the Irish Sustainable Energy Authority (SEAI) provided inputs to the model. The model outputs were compared to the actual Irish energy system output data in terms of electricity, heat, fuel production and emissions. The model was thus benchmarked against SEAI's most recent available energy balance for the Irish system and found to be in good agreement. The validated model was then used to model the current objectives and aims specified by the Irish Government, the ESB and Eirgrid for development of the Irish energy system towards 2030. We have shown that the planned changes to the Irish energy system are insufficient to meet Ireland's 2030 renewable energy target (32% renewable energy contribution to primary energy supply), it would instead produce 23.4%. We have proposed an alternative pathway to achieve Ireland's 2030 renewable energy targets with the following technologies to improve inter-connectivity of the various sectors across the energy system: (1) Vehicle to Grid (V2G) technology for electric vehicles (vehicles remain grid connected), (2) District heating systems powered by Combined Heat and Power (CHP), large-scale heat pumps and thermal storage, (3) Power to Gas (P2G) to fuel heavy vehicles, freight and aircraft, and further for electricity storage.

Keywords: Energy systems modelling; Ireland; 2030; EnergyPLAN; Energy policy; Energy systems

Kun Zhu is a PhD fellow from Sustainable Energy System group at Aarhus University, who seeks the cost-effective transition pathways to reduce GHG emissions in European energy system.

Go or wait? The impact of emission pathways on the European energy system transition under myopic planning

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As reported by "Global Warming of 1.5ºC" from the International Panel on Climate Change (IPCC), it has never been more urgent to drastically reduce anthropogenic greenhouse gas (GHG) emissions in the energy system. In alignment with the 1.5°C scenario, the European Commission has provided a long-term strategy for a climate-neutral Europe by 2050, guiding towards net zero or even negative emissions. The reduction pathways proposed in the report imply deep decarbonisation in the early stage, despite the fact that inadequate existing infrastructure today. On the one hand, delaying decarbonisation actions may result in a cheaper energy system due to falling costs of low-carbon technologies, especially wind and solar. On the other hand, too low GHG emission targets in the short-term might yield to a more expensive system because of lock-in effects in wrong investments. Based on current infrastructure, we model the European sector-coupled energy system in hourly-resolved one-node-per-country network, undergoing a myopic planning. Three distinctive emission pathways are defined, namely baseline, delay, and instant, yet sharing the same amount of GHG emission budget by 2050. We aim to quantify the extra costs or benefits by delaying or accelerating emission reduction pathway, as well as to identify the feasibility of renewable expansion during the transition.

Keywords: European energy system; Sector coupling; Transition pathway; Myopic planning

Kristoffer Steen Andersen is PhD fellow at DTU and advisor at the Danish Energy Agency. His research focuses on linking energy system models with macroeconomic general equilibrium models to provide comprehensive assessment of climate and energy policies.

To EE or to VE: Interaction between VE and EE in meeting long term climate policy

Kristoffer Steen Andersen *(presenter)*
Danish Energy Agency

This paper studies the trade-off between energy efficiency (EE) and renewable energy (RE) investments in a Danish climate policy context. This trade-off reflects that increasing investments in EE reduces the need to invest in RE technologies, by virtue of lowering final energy demand. On the other hand, if RE investments lead to lower fuel prices households and industry would have less of an incentive to invest in EE. Understanding this trade-off is of key importance to policy makers, assuming that resource needed to meet long-term climate policy goals are scarce. The paper uses the Danish energy system model (TIMES-DK) to capture the trade-off between EE and RE investment. TIMES-DK optimizes the level of EE and RE in a reference scenario, assuming actual market behavior and no additional policy. Hurdle rates are used to capture actual investment behavior of energy companies, industry and households. The paper develops two comparative scenarios on top of the market reference scenario. The first scenario determines what happens to optimal level of investments in EE, when investment in RE are increased exogenously? The second scenario, conversely considers what happen to optimal RE investments, when EE investments are increased exogenously? The paper then concludes on the extend RE and EE investments interact TIMES-DK, and what this signifies in terms EE and RE policy design.

Keywords: Energy efficiency policy, renewable energy policy, energy systems modelling

The writer **Roberto Bricalli**, is an Italian student in MSc Mechanical engineering at Aarhus University. After his bachelor in Switzerland (SUPSI) he decided to move to Denmark to broaden his horizons and knowledge specifically in the energetic field, which has always been his focus on his studies.

Impact of climate change on long-term planning of electrical systems based on renewable sources in Europe

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Development of the European electrical system is making countries favour electrical complexes with a larger sustainable source's penetration, making them more weather dependent. It is therefore relevant to analyse how climate change could affect our electrical production and consumption. This paper aims to give an answer to issues that climate change could raise in long-term planning of renewable electrical systems. We apply high-resolution weather data from 4 regional climate models downscaling 6 global climate models under the forcing of 3 CO_2 concentrations pathways under the EURO-CORDEX project, extending the analysis by Kozarcanin et al (2019) published in Joule. Based on the weather data, wind and solar power generation and consumption profiles are calculated for 30 European countries. Calculating this high-resolution data allowed us to compute variations, based on the penetration rate of adopted sources, of five key metrics in renewable electric systems of the period 2080-2100. The focus is on the overall results of the climate models evaluated through their average, confirming previous literature on the subject. Overall, these results indicate that climate change will not affect the electric system more than the annual general variation. There is however, one exception to this, as the benefit of storage, for high penetration of solar power, presents in the most intense CO_2 concentration pathway a reduction of 5% compared to the current annual variation of 2%.

Keywords: climate change; large-scale renewable electricity systems; wind power; solar power; IPCC; electricity production; electricity consumption

Professor **Gram Mortensen** has been engaged in the legal aspects of the energy industry, including both upstream and downstream. He has written and contributed to a large number of articles and books in English, Danish and German. He is among others vice chairman of the Danish Energy Board of Appeal

Purpose limitation for smart metering data

Bent Ole Gram Mortensen *(presenter)*
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District heating is used at various geographical scales, where heat demand is dense, and heat sources are available at low costs. However, both dimensions may offer economies of scale through interconnection. This may reduce specific generation and distribution costs. Access to low-enthalpy excess and geothermal heat sources may facilitate the expansion at larger geographical scale, while improving end-use efficiency. The paper aims at identifying techno-economic potentials for the development of district heat clusters, where smaller and larger systems can share common supply, increasing the utilisation of excess heat and geothermal resources. The Pan-European Thermal Atlas and the findings of the Heat Roadmap Europe project are used to analyse scaled-up district heating in the European heat sector. Geothermal heat potentials and costs are mapped, and potential sources of industrial and other excess heat are quantified and located. Network allocation minimizes transmission routing, and supply of heat is balanced against the infrastructures needed. About 300 clusters of prospective and existing district heating systems are identified, for which costs of district heating distribution and transmission grids are modelled. Geothermal and excess heat sources are allocated in a least cost manner. Results identify significant potentials of low-grade heat supply to district heating. Interconnections to clusters offer a significant economy of scale.

Keywords: Smart metering, GDPR, purpose limitation

Christian Thommessen studied mechanical and business engineering at the University of Duisburg-Essen. Since 2017 he is PhD student at the Chair of Energy Technology and focusses on district heating systems and the optimization of operation – from supply through distribution to consumption.

An innovative concept to increase the efficiency of existing combined heat and power plants in developing district heating systems

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Combined heat and power (CHP) plants are the main supply source in district heating systems (DHS). Since system operators aim at expanding the infrastructure and increasing the number of customers, existing plants have to face different supply challenges during their lifespan. On the one hand, new buildings usually have higher insulation standards and on the other hand, already existing buildings are modernized by their owners, e.g. because of incentive programs. Both imply lower heat demands, whereas the supply area enlarges. The contribution of this paper is an introduction of a new concept to harmonize the district heating operation in urban areas with unsteady heat demand patterns due to new and old buildings. Today, DHS with CHP plants operate at supply temperatures around 90 to 120 °C depending on the time of the year and the ambient temperature. However, efficiency is a problem as CHP plants have a loss rate around 15 to 20 percent, e.g. waste heat of mixture coolers remains unused due to lower temperatures. The idea of the new concept is to transform the existing DHS into separated infrastructures with different and (much) lower supply temperatures. The first "LowEx"-part of the DHS can be operated at temperatures around 20 to 30 °C. The second part of the network can also operate at lower temperatures around 80 °C. This allows the whole system to integrate more renewable sources and to operate existing CHP plants more flexible and efficient by using more waste heat.

Keywords: Cogeneration, District Heating, Renewable Energy Sources, Supply Temperature Reduction, Building Insulation

Paolo Leoni, has been working as Research Engineer at AIT Austrian Institute of Technology GmbH in the fields of District Heating and Cooling and Integrated Energy Systems since 2016. Before, he worked as Project Manager and Engineer for biomass, geothermal, solar thermal power at Enel (Italy).

Developing innovative business models for reducing return temperatures in district heating systems: approach and first results

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The deep implementation of measures for substantially reducing the operating temperatures is one of the crucial challenges in most of the existing European district heating systems. Temperature reduction plays a key-role in increasing the energy efficiency of the system and, most important, allowing a higher and more cost-efficient integration of sustainable low-temperature sources. The present work illustrates the methodology and the first results of the ongoing Austrian project T2LowEx: the project intends to identify new possible stakeholders, key-activities, financing mechanisms, tariff structures, customers' engagement strategies, and set up innovative business models encouraging the implementation of customer-side optimization measures for reducing the return temperatures. Objects of the study are both urban and rural district heating systems. The approach consists of the following tasks: a) identification, based on real data, of cost-efficient measures to reduce return temperatures in existing systems; b) cost-benefit analysis; c) stakeholders' mapping; d) workshops and interviews with the stakeholders. The importance of an approach oriented to customer-side measures is underlined by the real-data analysis, showing that the network operator results responsible in barely 11% of the cases, while, in the remaining 89%, the responsibility lies on the customer side.

Keywords: district heating, business models, energy savings, cost-benefit analysis, 4GDH

Richard van Leeuwen is a Professor of Sustainable Energy Systems with a PhD in Smart Energy Systems

Towards municipal heat solution strategies

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In the Netherlands, municipalities and regional energy planning working groups are challenged to develop plans for municipal and industrial "heat transition": from natural gas towards renewable heating systems.
However, an interesting issue continuously comes up: when to opt for a district heating network (invest in infrastructure) or to opt for individual solutions (invest in renovation measures and heat pumps)? With examples from the Netherlands we show that in many cases the choice of a heat solution in a municipality is not based on rational arguments but is often dictated by (expected) financial profitability. A narrow route is often followed in which the feasibility of a prefered heat solution is first investigated and then it is decided whether or not to proceed to a planning phase for that solution. Comparing alternatives as part of an integral assessment is often not done in a fair way. An important reason for this is the complexity of making a proper assessment of alternatives.

So the essential question is: how can municipalities decide rationally on which heat transition concept is the most preferable alternative for an urban area?

In our contribution we present a decision support tool consisting of a step-by-step approach and a conceptual model for mapping heat supply options including conditions, technical challenges and associated market organization issues. With an example we demonstrate how the tool can be used and argue that working with the tool can lead to better quality decision making than current practice. Because the development of the tool is still "work in progress", we end with a dialogue with the audience to come to new insights for further research.

Keywords: heat transition, renewable energy integration, district heating, heat pumps, thermal storage, waste heat utilization, 4th generation district heating

Zhikun Wang is a doctoral researcher at the Bartlett School of Environment, Energy and Resources, University College London. His research interests lie in the fields of energy economics, decarbonisation in the heat and power sectors, and energy and environmental policies.

Sizing of district heating systems based on smart meter data – Understanding aggregated domestic energy demand in Great Britain

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The sizing of district heating systems involves a trade-off between reliability and avoidance of costs associated with oversizing. Finding the most appropriate sizing requires a thorough understanding of energy load profiles. However, empirical data necessary to support such an understanding is scarce. This study gathers weather and smart meter data from over 18,000 households to analyse energy demand in British dwellings. Results illustrate the seasonal and daily variations in aggregated energy consumption patterns, the weather dependence of energy loads, and peak hourly energy loads under exceptionally cold weather conditions. This study also explores the diversity effect in energy consumption on the district level. Results find that peak hourly gas consumption was nearly seven times higher than electricity consumption during the cold spells, while diversity reduced the aggregated gas and electricity peak demand up to 33% and 47%. With empirical bases, results from this study can be applied to support district heating designs and operations, especially in forecasting demand, planning load control mechanisms and organising economic grid operations, to ensure infrastructure reliability while reducing costs and mitigating the risks of over- or under-sizing and interruptions in services. Further, this quantitative analysis can be utilised to develop and validate energy models, evaluate investments, assess contracts and tariffs, and regulate energy generation and purchasing.

Keywords: load profiles; peak demand; energy demand diversity, district heating sizing

Michiel Fremouw (TU Delft) studies the spatial quantification of renewable energy, application in energy atlases and the relations with urban transition strategies. He has contributed to, amongst others, the European CELSIUS, City-zen and PLANHEAT projects.

How LowEx can you go? Validating the PLANHEAT (D)HC toolkit at the TU Delft campus

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The PLANHEAT project (H2020) is developing a QGIS based, open source (D)HC toolkit to help planning authorities make informed decisions on their future heating and cooling systems. Delft University of Technology is building a roadmap to achieve CO2 and energy neutrality on their campus in 2030. The university manages the majority of their campus assets and infrastructure, including a DH network, and various innovative energy systems have already been deployed. They therefore own an extensive dataset, which will be used until summer to validate the algorithms applied in the toolkit. Conversely, the PLANHEAT toolkit will be used to help develop the roadmap.

Keywords: Energy Potential Mapping, LowEx; HC planning; transition roadmap;

Paula Ferreira is Associate Professor - School of Engineering, University of Minho and Researcher at ALGORITMI Research Centre. Her research interests are in the multidisciplinary approaches for energy planning and for sustainability assessment of industrial and energy systems.

The importance of demand response for low carbon energy scenarios

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Research on energy modelling and long term scenarios construction has been mainly focused on energy supply options and technologies, but there is growing evidence that demand-response (DR) can also have an important role on low carbon pathways and smart energy system. A few studies based on optimization and simulation scenario building already demonstrated the significance of DR for reducing costs, increase renewables capacity and reduce thermal power output in operation and strategic power planning. However, the key role of the consumer for the effective implementation of these DR programs is still far from being fully considered in the energy system analysis. This paper will address both these topics with particular emphasis on the case of the Portuguese electricity system. Firstly, by revisiting the studies which addressed the role of DR in the long-term energy modelling. Secondly, by discussing the results of a recent survey on Portuguese population which analysed to what extent and under which conditions consumers are willing to engage in DR programs. The results put in evidence the importance of DR, for ambitious renewable targets, but highlight also the need to overcome the frequently dominated techno-economic thinking, for both energy modelling and technology development.

Keywords: Demand response; Willingness to participate; Energy modelling

Géremi Dranka is Assistant Professor at the Department of Electrical Engineering in the Federal University of Technology, Brazil. Currently, he is a Ph.D. student at University of Minho. His research interests are in the energy planning and multidisciplinary approaches for energy.

Demand Response Potential in Brazil: Theoretical Assessment

Géremi Gilson Dranka (presenter), *Paula Ferreira,*
University of Minho

The flexibility in grid operations has become a valuable solution to address the several problems brought about the growth of intermittent renewable generation especially from wind and solar power. The use of Demand Response (DR) measures has emerged as a potential contributor to address this challenge for the development of a smart energy system. To the best of authors knowledge, the assessment of the theoretical DR potential for the Brazilian power sector has not yet fully addressed in the literature. Therefore, this paper is a first attempt to establish the theoretical DR potential for the Brazilian power sector across the residential, commercial and industrial sectors. The strengths of this study include two central issues addressed: (1) a sectoral analysis (i.e. residential, commercial and industrial) and (2) a regional analysis by broadly splitting up the Brazilian power system into four main subsystems. Our findings reveal that the overall maximum hourly theoretical DR potential in Brazil is expected to double, increasing from 12.8 GW in 2017 to almost 25.6 GW by 2050. This study also points out that the majority DR potential may lie in the industrial sector. Lower but a still substantial potential for the residential and commercial sectors were also identified. The high expected increase in the overall electricity DR potential for the residential sector is driven mainly by the increase in both the number of households and the number of appliances per house.

Keywords: Demand Response (DR), Theoretical DR Potential, Brazilian Power Sector.

Throughout his PhD studies, **Rasmus Elbæk Hedegaard** has worked on investigating and documenting the potential of utilizing the energy flexibility that can be provided in buildings. He is currently in a postdoc position where he models the flexible demand on clusters of buildings.

Investigation of the energy flexibility potential of Danish residential building archetypes

Rasmus Elbæk Hedegaard *(presenter)*[1], *Martin Heine Kristensen*[2], *Steffen Petersen*[1],
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In recent years, a significant number of studies have indicated a potential of leveraging the thermal mass in buildings to generate flexible energy demand through demand response schemes. This flexible demand may be used to absorb the daily consumption peaks that occur in district heating (DH) networks. These studies have shown that newer and more energy-efficient buildings generally are also more efficient at utilizing the thermal mass for energy storage. However, the lower consumption in these buildings mean that they have a relatively low storage capacity and are therefore not able to provide the same quantity of flexible energy consumption as less energy-efficient buildings. This gives rise to the question of whether neighborhoods populated with different building typologies are equally capable of leveraging flexible consumption to lower the capacity requirements that apply during both the daily operation and initial sizing of DH networks. In this study, we use stochastic archetype models of the district heating demand of single-family houses (i.e. space heating and domestic hot water) to investigate the flexibility potential of neighborhoods composed of different building typologies. Using coordinated optimization to determine the heating strategy in the residential buildings, we document the extent to which these neighborhoods may apply flexible space heating consumption to adapt their overall consumption in favor of the DH network.

Keywords: demand response; district heating, energy flexibility characterization, smart meter data, hourly time series; building energy modelling; archetypes; single-family houses; neighbourhoods

Sara Månsson's main research interest is the interface between data and reality in the DH sector. Specifically, the focus is to identify and handle issues in the district heating systems by combining results from data analytics with knowledge of district heating substations, system operation, and buildings.

Validation of fault detection methods for district heating customer installations

Sara Månsson (presenter)[1,2], Marcus Thern[1], Per-Olof Johansson Kallioniemi[1], Dirk Vanhoudt[2,3], Robbe Salenbien[2,3], Tijs Van Oevelen[2,3], Kerstin Sernhed[1],
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District heating (DH) has been identified as an essential part of future, smart energy systems due to the ability of such systems to make use of heat that would otherwise go to waste. Capturing this waste heat requires that the DH systems reaches their full potential and operates as energy efficient as possible. Current DH systems contain a number of issues that cause the efficiency to decrease, and one of them is that customer installations in the systems are utilizing the heat in a poor way. This results in higher return temperatures than necessary. It is therefore important to detect poorly performing customer installations rapidly so that their performance may be improved. There are several ways of detecting and diagnosing faults at customer installation. In this case study, two fault detection methods developed in previous studies were implemented and tested for a DH-system located in Sweden: an automated statistical method and a method based on a machine learning approach. The customer installations that were identified as poorly performing were further investigated using both customer data and physical visits to the installations. This made it possible to investigate what fault was present in the poorly performing installations. The results include an overview of the most frequently occurring faults in the customer installations that were detected using the fault detection methods, and an evaluation of the two fault detection methods in terms of accuracy and validity.

Keywords: District heating customer installations, Fault detection, Fault diagnosis, Validation

Shahrooz Abghari is a PhD student in computer science at the Department of Computer Science at Blekinge Institute of Technology, Sweden. He received his M.Sc. degree in computer science in 2013. His research interests include clustering analysis, data mining, and outlier detection,

Data Analysis Techniques for Monitoring District Heating Substations

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We propose a combination of data analysis techniques for monitoring the performance of DH substations on weekly bases. We combine sequential pattern mining together with clustering analysis and minimum spanning tree (MST) to identify outliers. The main idea is to detect changes in operational behaviour of a DH substation that can deteriorate its efficiency. We initially extract weekly frequent patterns and group them based on their similarities into clusters which model the substation operational behaviour. In the next step, we compare the DH substation behaviours for every two consecutive weeks. This is performed by integrating the produced clustering solutions into a consensus clustering. In addition, we can assess the similarity between the clustering solutions generated for each two consecutive weeks and consequently for the whole heating time period. The conducted assessments can be used to create a performance signature profile of the substation. Such signatures can also be applied for comparison of substations that belong to the same heat load category. Finally, we can apply the MST algorithm which builds an MST by considering the exemplars of the consensus clustering solution as nodes and the distance between them as edges. Notice that an MST is a tree with a minimum traversing cost. In order to identify unusual behaviours, we cut the longest edge(s) of the MST. Smallest and distant sub-trees can be considered as outliers.

Keywords: District Heating Substations, Clustering Analysis, Minimum Spanning Tree, Data Mining, Outlier Detection

Weronika Radziszewska received her PhD in computer science 2015, the topic of the thesis was intelligent distributed system for flexible management in microgrids. Her research interests include agent approaches, theory of communication, power storage and development of market strategies.

Testing of a price-based decentralized system for power balancing on real-life HVAC installation

Weronika Radziszewska (presenter)[1]*, Marcin Bugaj*[1]*, Mirosław Łuniewski*[1]*, Gerwin Hoogsteen*[2]*, Patryk Chaja*[1]*, Sebastian Bykuć*[1]*,*
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The paper presents a real-life experiment of applying a market-based distributed method of power balancing in a real installation in the KEZO Research Centre. The centre is equipped with HVAC system consisting of waterloop installations, PVs and power storage units; all are connected to common building management system. The aim of the research is to develop a working microgrid using the available equipment with the focus on the optimization of power use in heating and cooling systems. In this stage, a test case scenario is presented where the distributed auction-based system successfully manages changing the operating point of the waterloop units to limit the use of power to some defined value. For the experiment, we use 10 heat pumps responsible for temperature control in 10 comparable-size rooms. The market-based distributed system assigns each device a cost-curve that is parametrized with the current temperature of the room. The algorithm balances the consumption of power with the available shared supply. In the study, we artificially limit the available power to see the behaviour of the algorithm, but also the live behaviour of the heat pumps as well as the observed resulting temperature change in the rooms. The test allows to estimate the minimal power requirement for this limited set up that will still allow maintaining internal temperatures in comfortable levels.

Keywords: Waterloop, HVAC management, distrubuted management, market algorithm

Working as a Project manager at Kraftringen, Lund, **Sara Kralmark** is involved in many cutting-edge projects in the field of energy - district heating, electricity and lighting. Sara has a master's degree in environmental engineering from Lund University.

Introduction to COOL DH

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COOL DH is a four-year project funded by the European research and innovation program "Horizon 2020" including representatives from Sweden and Denmark. The aim of the project is to develop and demonstrate new solutions for low-temperature district heating (LTDH) and to spread the knowledge throughout Europe. Today's European DH is a sustainable heating option, dominated by heat originating from incineration of biomass residues and waste. However, with new DH technology, it is predicted that so-called waste heat can accelerate the energy transition even further. Also, DH that utilizes low temperatures is advantageous especially in areas with low energy buildings. In the Copenhagen suburb Høje-Taastrup, a DH network with a supply temperature of 55 °C will replace an old DH system in an existing residential area. In the new city district Brunnshög in Lund, Sweden, a LTDH network with a supply temperature of 65 °C is built. As a complement to these construction projects, COOL DH offers opportunity to innovate and do research on new pipe technologies, business models, ways to reduce the risk of bacterial growth in LTDH systems and to optimize heat production as well as distribution. If a whole session: This session includes a general presentation of the COOL DH project followed by shorter presentations on a selection of project topics; the development of plastic pipes, the DH customer perspective and the challenges of convincing the locals in Høje Taastrup to change into LTDH.

Keywords: Waste Heat, Grid Temperature, COOL DH, LTDH, Hoje-Taastrup, Renovation, Sustainability, Brunnshog

Steen G Olesen is a specialist in energy efficiency and quality assurance with over 20 years of experience in private and public companies/authorities. He has been involved in ambitious climate and energy activities in Denmark and deeply involved in the ECO-Life project as the local community coordinator.

How to convince the locals to change to LTDH, Østerby example

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How do you convince house owners or tenants to accept low temperature (55/30 LTDH) district heating when they barely know what make them have the daily hot shower and keep them warm in the winter time? Fronted by the costumer owned utility company Høje Taastrup Fjernvarme and in close collaboration with Municipality of Hoeje-Taastrup and COWI A/S more answers have been found to the question as part of the innovation action project COOL DH implemented from 2017 to 2021. Østerby is an area consisting of 159 terraced houses, a public kinder garden and a social housing company with a total of approx. 36.000 m² building stock. The area was developed in the 80'ties, and with the original 35+ years old direct DH system in place. The tenants of the terraced houses are organized in three housing cooperatives and one owner association. After numerus meetings in 2018 they decided to accept the offer. During 2019 they will all have newly developed (LTDH SH/DHW) units installed, newly developed high-pressure polymer flex pipes with a supply of heat based on surplus heat from cooling machines running on electricity produced on a large PV installation in the nearby shopping mall CITY2. Environmental awareness and sustainability count for long in the decision process, but not in the final stage where the upfront investment cost is the key to convince the locals.

Keywords: Waste Heat, Grid Temperature, COOL DH, LTDH, COWI, Hoje-Taastrup, Renovation, Sustainability

Klaus G Lauridsen is working as a Senior Product Manager at Logstor, Denmark, Klaus is playing a main role in the transition to the next generation DH. Klaus has an engineering exam and has worked for Grundfos for many years, Before joining Logstor in 2017.

Development of a 4th generation District Heating preinsulated piping system

Klaus G Lauridsen (presenter)

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Standard pipe systems today is preinsulated steel pipes. Minimum requirements to the preinsulated components and system is defined in the European standards. With a low temperature system running between 55 -85 0C the calculated lifetime of the pipe system is far beyond 1000 years. For a low temperature 4th generation District Heating system this is over engineered and too expensive. We need to start pushing for an updated standards that fit the real needs. LOGSTOR is within the frame of COOL DH developing a preinsulated pipe system using plastic pipe as media pipes. This development will be presented during the presentation.

• Oxygen and Water vapour diffusion barrier in sizes up to minimum 110 mm media pipes.
• Preinsulated pipes in 100 m coils or 12 m straight length that match the needs for modern low temperature systems.
• High insulation properties.

Easy way of connecting the pipes and with options of leak detection. How far are we to a real alternative to preinsulated steel pipes?

Keywords: Waste Heat, Grid Temperature, COOL DH, LTDH, Logstor, Pipes, Plastic pipes, Development, Research, Renovation, Sustainability

Born and raised in the Netherlands, **Dennis Kerkhof** moved to Sweden thanks to the Power of love. He now works as a Construction manager at LKF, the municipality owned Construction Company in Lund, Sweden.

Xplorion - energy efficient building using low temperature district heating

Dennis Kerkhof (presenter)

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An important focus for LKF is to create long-term stable opportunities for a continued high rate of new constructions. Already in the early stages, both economic, social and environmental sustainability are taken into account. In Xplorion new smart technologies for low temperature district heating, flexible planning, local energy production and more are tested. If the tests are positive, LKF can raise the bar on all its future new production. In Xplorion a complete system that uses low temperature district heating will be tested. The idea is that residual heat at a low temperature (30-60 ^{o}C) will be raised in the building (to 60-65 ^{o}C) and sent to a storage tank. If necessary, hot water is delivered to the apartments where there is one heat exchanger per apartment – a flat station. This flat station takes care of both the heating and hot water requirements. The used water is returned either back to the storage tank/heat pump or to the DH return line, depending on temperature. With flat stations, no hot water circulation is needed. It also allows for individual metering of heat and hot water usage. Considering the amount of residual heat, the dishwashers get a hot water connection that reduces the electricity consumption for the dishwasher by about 35%. During the COOL DH demonstration project, LKF and Kraftringen will try new solutions linked to LTDH, for example new innovative piping in the building and evaluation of the "3 liter rule" to avoid Legionella.

Keywords: Waste Heat, Grid Temperature, COOL DH, LTDH, LKF, Brunnshog, Smart buildings, Sustainability

Klara Ottosson has a master's degree in Environmental Engineering from Lund University. After writing her master thesis about Legionella in LTDH-systems at Kraftringen in Lund, she is now working as a project engineer within distribution of district heating.

Heat driven appliances

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Substituting a part of the electricity used to power appliances like dish washers and washing machines to low temperature district heating is an interesting way of reducing electricity consumption and increasing the share of renewable district heating, particularly in areas with large amounts of available residual heat. When speaking about heat driven appliances it is mainly dishwashers, washing machines and tumble dryers with integrated heat exchangers that are referred to. Theoretically, such appliances, driven by the hot water circuit, can reduce the electric energy use of more than 50 %. The highest saving is for washing machines, with a potential 74 % reduction of the electric energy use. Heat driven appliances were developed by the company Asko and required at least 55 ^{o}C. Af they were never commercialized and the development ended in 2014, further research might help reducing the temperature requirements, as there is a huge potential for electric energy savings.
Available on the market today are a few dishwashers and (professional) washing machines that can be connected to hot water. Such machines requires resistant hoses and, for washing machines, two inlets, not making all of the products suitable for such a solution. The hot water connected appliances reduces the use of electric energy, but not to the same amount of heat driven appliances – which is why a continued research on such appliances would be interesting.

Keywords: Waste Heat, Grid Temperature, COOL DH, LTDH, Sustainability, Heat driven appliances, Appliances, electricity savings

David Edsbäcker holds a MSc in Energy Systems and works with buisness development at the Energy Supply Company Kraftringen. He is Kraftringens project manager of the ongoing project Smart Cities Accelerator.

Securing a lower grid temperature through increased digitalization -Using heat load forecasting and feedback from the grid

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To utilize the excess of waste heat at low temperatures, district heating (DH) companies need to shift from high-temperature 3rd generation DH to lower operational temperatures. Local boosters might be used to adapt the waste heat to a desirable temperature, but this is energy demanding and costly. By optimizing the temperatures in existing DH networks, the demand of local boosters will decrease. As more real-time data becomes available, more parameters can be considered, allowing reduced temperatures. Within the project Smart Cities Accelerator (SCA), the possibilities of temperature optimization using a digital software has been investigated. The software adjusts the grid temperature depending on weather forecasts, flow limitations and critical points in the grid. The critical points are generally located in the outskirts of the grid and receive a lower temperature due to distribution losses. This fact can be used to control the overall grid temperature: By using real time data from these points with limitations on flow and temperature it's possible to ensure that the remaining grid receives a sufficient heat delivery. The software was installed in Lund's DH grid in March 2019 and during the first month of operation the grid temperature was on average reduced with 4 °C. For the DH grid of Lund municipality, with an annual heat delivery of 900 GWh/year, the saving is estimated to 1 M.SEK per degree of temperature reduction and year.

Keywords: Waste Heat, Grid Temperature, Real Time Data, Optimized District Heating Delivery, SCA, Digital Software, Critical Points.

Goran Krajačić is assistant professor at the DEPEE (UNIZAG FSB). He defended his PhD thesis at UNIZAG FSB in 2012. Since 2002, he has been member of LOC of SDEWES Conference and worked on many EU projects including KeepWarm. Results of his work are published in more than 30 papers listed in CC/SCI.

Techno-economic analysis of upgrading heating systems into sustainable DHS

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Heating and cooling sector in Europe accounts for half of the energy consumption and most of the required energy is still generated from fossil fuels. Since Croatian district heating sector dominantly relies on fossil fuels, decarbonization of the sector and introduction of RES is necessary. The combination of district heating with solar thermal energy, heat pumps and heat storage has successfully reduced fuel consumption and carbon emissions on several locations in Europe, especially in Denmark. In the same time, significant progress in RES integration into district heating in Croatia is not observed. In this study, a techno-economic analysis of RES integration on the system with yearly heat consumption around 50.000 MWh has been conducted with respect to local conditions in pilot city of Velika Gorica. Several different scenarios, suggested by KeepWarm project, (combining solar thermal, heat pump, cogeneration and heat storage) are investigated in pursuit of optimal shares of RES which result in highest profitability.

Keywords: District heating, RES, solar thermal, heat storage, heat pump

Hiroyasu Shirato

Development and Application of New Heat Supplying Systems Utilizing Hot Spring Water in the Northern Island of Japan

Hiroyasu Shirato[1] (presenter), Takahiro Suzuki[1], Tetsuya Takahashi[1], Hideo Hoshina[1], Takumi Fujisawa[1], Toshiyuki Akazaka[1], Takamitsu Sakuraba[2], Tomoaki Iura[2], Hidekazu Yamada[2] and Yasuo Nakata[2]

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Hot spring water is an important renewable heat source. The utilizable energy of hot spring water in Hokkaido, a northern island of Japan, as a heat source for district heating systems was mapped by using the GIS technique. For utilizing hot spring water and preventing water leakage and corrosion of heat exchangers, a palisaded heat exchanger combined with plastic pipes using thermal fusion bonding was newly developed and could be applied for heat recovery system from the hot springs.

Keywords: Utilizable energy of hot spring water, Palisaded heat exchanger combined with plastic pipes

Introduction

Hot springs are not only well used in spa facilities for relaxation but are powerful renewable heat sources. There are about 2,200 hot springs in Hokkaido, the northern most island of Japan. Especially, the hot springs which has a temperature of more than 313K (40℃) can be considered as heat sources for district heating systems. In this presentation, we show the utilizable energy of the hot springs for district heating systems in Hokkaido. Next, we point out some technical problems and introduce a new type of heat exchanger.

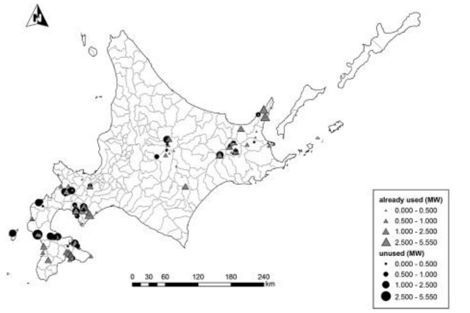
Utilizable energy of hot spring water as a heat source for heat district systems

The number of hot springs sites in Hokkaido is 245, the total emission amount of the hot springs water is 2,110 m^3/min. About 59% of the hot springs are more than 315K(42℃)[1]. Figure 1 shows maps of the utilizable energy in Hokkaido we can use for 4GDH by using the GIS technique. The amount of the utilizable energy (for 4GDH) was calculated by the equation (1).

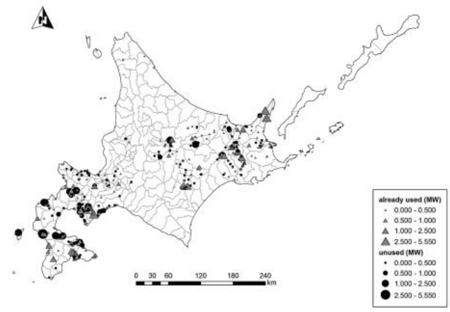
$$Q=1/1000\times C_p\times \rho\times F/60\times(T_{out}-313) \qquad (1)$$

Q: Amount of the utilizable energy [MW]
C_p: Specific heat of hot spring water≒4.2[kJ/kg・K]
ρ: Density of hot spring water≒1.0[kJ/kg・K]
F: Flow rate of hot spring water [L/min]
T_{out}: Discharge temperature of hot spring water[K]
313: Temperature for heating[K] (40℃)

In the Figure 1(a), there were 40 already used sites where more than 1MW of the thermal energy was indicated as the utilizable energy. On the other hand, 11 sites were shown for unused hot springs. Whether already used or not, the sites shown for more than 1MW were concentrated in the eastern area or the western area. In the Figure 1(b), several sites for already used, and a few sites for unused were added for more than 1MW (46 sites for already used, 12 sites for unused).



(a) Calculated from more than 333K(60℃) of hot springs



(b) Calculated from more than 313K(40℃) of hot springs

Figure 1 Maps of the utilizable energy of hot springs in Hokkaido, the northern most island of Japan

Even if we see the large amount of energy from figure 1, there are technical problems to correct from the hot springs. A lot of suspended solids are the issues we should solve when we recover the heat from the hot springs because recurrent dissolution and cleaning of the surface of heat exchangers should be carried out frequently using the plate or the shell and tube type heat exchangers, in which water passes throughout. Moreover, heat recovery using metal heat exchangers form the hot spring water at low pH values may cause water leakage because of metal corrosion. Though the pH values of 80% of the hot springs in Hokkaido are 6.1～9.0, the values of 8.7% are less than 3.0. 33% of hot spring water contains more than 3g/L of suspended solids.

Palisaded Heat Exchanger combined with Plastic pipes [2]

Now we designed a new tube type palisaded heat exchanger combined with corrosion-resistive and easily washable plastic pipes to collect the energy from the hot spring water. Figure 2 shows a typical example of prototype heat exchanger. All materials of the heat exchanger were polypropylene. The heat exchanger had two units which sandwich alternately. The units consisted of eight or nine panels connected by connection horizontal pipes via narrow pipes bonded by thermal fusion bonding. The panels were also formed by thermal fusion bonding between 40 narrow longitudinal pipes and the upper and the lower horizontal header pipes. The pitch of the narrow pipes was 20 mm.

The heat exchanger was soaked in a tank where the hot spring water streamed while well water or tap water inside the heat exchanger was warmed by the heat from the hot spring water. The tank could be made of concrete of FRP. Figure 3 shows the appearance of the heat exchangers soaking in tanks in test fields for hot water preheating systems in spa facilities. Now we are trying to design and install the heat exchanger for heat energy network systems among several facilities (Figure 4) and district heating systems.

Figure 2 Appearance of the palisaded heat exchanger

Figure 3 Heat exchangers soaking in tanks

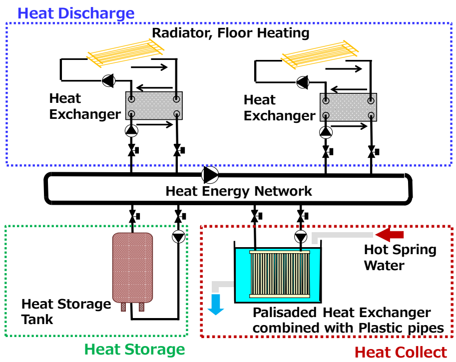


Figure 4 Heat energy network system using hot spring water

Conclusion

Already used in 46 sites, and Not used in 12 sites of the hot springs in Hokkaido, the northern most island of Japan, were shown as the sites that more than 1MW of the utilizable energy existed. A palisaded heat exchanger combined with plastic pipes for preventing corrosion and clogging was newly developed and applied for heat recovery systems from the hot springs. Now we are trying to design and install the heat exchanger for heat energy network systems among several facilities and district heating systems.

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Shalika Walker is a Ph.D. candidate and is affiliated to the project "Smart Energy Systems in the Built Environment". Currently, she is working on the prediction of energy demand and analyzing the performance of buildings under the impact of clean energy initiatives.

Analyzing possibilities of using energy from surface and sewage water for the energy transition of the built environment - Study in the Netherlands

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With the arrival of the Environmental act in the Netherlands, municipalities are getting more responsibility for the energy transition which demands eventual disposal of fossil fuel-based energy systems. As alternatives, the focus of this study is on thermal energy from waste and surface water. Even though some studies have already shown the national and local energy potential with waste and surface water, for a lot of local policymakers, the energy potential and how and where it can be applied in their community is unclear. This study explored the current methods of extraction, storage and distribution of thermal energy from waste and surface water and how and where it can be applied in a local region (Breda). A potency map was made showing the monthly heating/cooling demand. The potential supply energy is calculated by using monthly averaged flow rates and temperatures based on measured data. The results show that currently a theoretical maximum of 41% of the heating demand for residential buildings can be supplied with energy coming from river water (surface water), and in the future, when the houses are more energy efficient, this could be 69%. However, the surface water potential seems quite high, as at the moment the whole river is being used. In reality, this percentage will be a tenfold lesser as the intake pump or heat exchanger will only use a small part of the river. For wastewater, the energy supply is lower with a current value of 25% and a future value of 44%.

Keywords: Aqua thermal solutions, Riothermie, Wastewater energy recovery, Aquathermie

Allan Oliveira is graduated in Oil and Gas Engineering, from Universidade Federal do Rio de Janeiro. 8 years experience in Production Engineering working for an operator company in Brazil. He moved to Denmark in 2018, and since then work with Geothermal Energy projects.

Low-Enthalpy Geothermal Heating Systems Modeling: Reducing Risks for Decision Makers and Consumers

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The attention to geothermal energy projects for heating purposes has been increasing in recent years as the need for clean energy sources grow. Although the recent growth, Geothermal still face big challenges as the risks of the investment are not well known due the limited number of plants in operation. The question is how can we contribute to unify knowledge and reduce investment risk to investor and consumers? In our vision, one of the actions to reduce the risks of the decision-making process is to generate basic assessment of the facilities, an accurate forecast of the energy production and detailed CAPEX/OPEX costs. In this way, taking the Danish market as a base scenario and gathering information from different service providers and geothermal plant operators, a project model has been developed. Using basic reservoir and heating systems inputs as temperatures as flowrates, the model can provide a concept screening for the facilities, detailed CAPEX/OPEX cost estimates, energy production and electric consumption forecast. Using the model investors can easily analyze the impact of different plant configuration, determine optimal number of production and injection wells, assess the impact of flowrates and temperatures variation on the energy production, estimate the breaking point for the operational hours and calculate the levelized cost of the produced energy.

Keywords: low enthalpy geothermal energy, district heating, maximize production, minimize risk and cost

Friederike Stelter

Trends of hybrid energy systems with the focus on power-to-heat technologies

Friederike Stelter (presenter), Niklas Gerloff M.Sc., Stefan Holler Prof. Dr.-Ing, Johannes Pelda, M.Eng.,
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One of the German government's energy goals is the reduction of carbon dioxide emissions by 90% by the year 2050 in comparison to the baseline in 1990. A significant potential opens up in decarbonisation of district heating (DH) systems, whose quantity of produced heat is based on 86% of fossil fuels. In this regard, the project DEKADE-F-Waerme which is funded by the German government aims at analysing different strategies to decarbonise DH systems in Germany, such as, the integration of industrial waste heat and renewable energies. The first part of the project aims at analysing and mapping technical information of DH systems in Germany as well as information about trend scenarios for district heating systems in 2050. For instance, the technical information about DH systems comprises heat sources, heat demand, network length and heat losses on a local level while the future scenarios shows the increase in DH demand for selected German cities in 2050 and possible options of replacing fossil fuels, e.g. by solar or geothermal heat and different power-to-heat applications. A database and GIS-map of German DH systems will be provided, which allows the categorisation of DH systems on the basis of specific key figures and enables users to request relevant technical information and data about DH systems in Germany for further modelling and simulation. In addition, integration of waste heat and renewable potential into the district heating network will be assessed in this work.

Keywords: district heating, trend-scenarios, waste heat potential, renewable energies, GIS-map

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A framework for energy performance assessment of a large BREEAM certified GEOTABS implemented in Kortrijk

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As the *2030 Climate and Energy Framework* of the European Unit foresees to achieves at least 40% cuts in greenhouse gas (GHG) emissions (from 1990 levels), at least 32% share for renewable energy and at least 32.5% improvement in energy efficiency by the end of 2030**.** In this context a large BREEAM certified GEOTABS have been raised in the city of Kortrijk, Belgium. GEOTABS stand for the combination of geothermal heat pumps and thermal activated building systems. During the construction process of the building, alongside the multiples feature considered by the BREEAM certification methodology, a holistic building information models (BIM) based approach have been applied to achieve high energy efficiency targets. The facility, known as EDC, is formed by two sections, the distribution and logistics building and the headquarter of the company which can be defined as an office building. Whereas many studies on energy performance of efficient GEOTABS are mostly based on medium and small size samples, in the current case 77000 m² of buildings are studied. The space heating demand using both floor and ceiling heating emissions concept is mainly cover by mean of several Heat Pumps which utilize for its operation a Ground Energy Storage field with capacity of 1 MW. While several Air Handle Units (AHU) becomes the secondary heating emission system. Moreover, thermal solar panels are used to satisfy the domestic hot water demand, meanwhile, to partially cover the electricity demand of the building, 15000 m² of photovoltaic panels accounting for 4,5 MW of capacity have been installed. Besides, when more data of the actual electricity demand of the whole facility will be known, the installation of a wind turbine in the nearby area is foreseen. In such a large building and energy system there often have been found differences between predicted (computed) energy performance and the actual measured energy use once the building is operational. This situation arises, due to the complexity to integrate the different subsystems and the difficulty of carrying out compatibles and not overrules control strategies implementation. The present paper deals with the formalization of a framework for the energy performance assessment of such a large GEOTABS by stressing the influence of relevant

parameters such as the performance of components (heat pump, ground heat exchangers, TABS, AHU etc.) to be able to quantify the impact in term of energy efficiency and savings, share of traditional and renewable sources, GHG emission savings. Characterization of the load profile in order to identify possible operational strategies related to priorities given to mains and/or secondary heat emission systems. Identifying the crucial elements when assessing the ground energy storage field performance when the ground is used as a heat source and/or a heat sink recommending possible seasonal control strategies to maintain the thermal balance in the ground on the long term meanwhile the heat losses impact in different section of the Ground Energy Storage field is considered. Therefore, the study aims to provide a comprehensive overview of the whole system in order to investigate whether the groundside possibilities of the geothermal system allow to cover a sufficiently large part of the heating and cooling loads of the building, so the higher investment costs can be compensated by lower operational costs. In addition, recommendations will be given for the follow-up and monitoring of each subsystem energy performance.

Keywords: Heat Pumps; Ground Energy Storage Field; Energy Performance Assessment

Alessandro Provaggi

What are the next priorities for innovation in Europe?

Alessandro Provaggi (presenter)
Euroheat & Power

Interesting times for Europe and energy policy in Brussels. The climate debate is high on the agenda and will push funding and support for energy innovation. Nevertheless, innovation support can take many different directions and the debate on the future “Horizon Europe” is still very open. There is a lot at stake. What will be the role of district heating, renewable heating and waste heat research in Europe? Will energy integration be the main driver in the next years? How to reconcile the assumption that funding for energy research is still essential with the fact that most barriers to the energy transition are non-technological?

Keywords: energy research policy, funding, district heating at EU level

Ari Laitala works as an education manager in Sykli Environmental School of Finland and is a team leader for the section Energy efficiency and property maintenance

Organizational challenges and possibilities for energy efficiency enhancement in the Finnish municipality sector

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In the Finnish project KIINTEÄ one of the goals is to support accession to energy efficiency agreement system (2017-2025) which is organised by Ministry of Economic Affairs and Employment of Finland. Biggest municipalities have joint to the agreement already but only few of the smaller ones. In project KIINTEÄ (2018-2020) piloting work will be done in city of Hämeenlinna and Helsinki parish which have joined to the agreement system but which don´t have the required action plan yet. In the project, framework for the action plan will be developed so that it could be exploited also in smaller municipalities and parishes. To enlarge and fulfill the basis of the action plan, other information sources need to be exploited, not only the piloting work. Sykli Environmental School of Finland performed a questionnaire in co-operation with the Association of Finnish Local and Regional Authorities in February 2018 to study energy efficient work bottle necks in the municipality sector. Number of responses was 102 which represents app. 30 % response rate. However, almost all the biggest municipalities answered, so the coverage of the municipal real estate stock is about 80 %. Results show somewhat clearly that main challenges for the energy efficiency work are 1) scarce personnel resource in preparation phase, 2) urgent actions needed to solve everyday problems like bad indoor air quality challenges plus 3) uncertainty of national level plan to reorganize social and healthcare services.

Keywords: energy efficiency, energy efficiency agreement, municipality, parish

Kirsten Hasberg is a PhD fellow at Aalborg University Copenhagen, where she focuses on institutional and regulatory aspects of blockchain-enabled peer-to-peer electricity markets in "The Energy Collective" research project. She holds a Master's degree in Economics from the University of Copenhagen.

Consumer-centric energy markets and distribution grid tariff reform: A review of the current debate in Denmark, Germany and the EU

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Distribution grid tariff reform is being discussed in several expert fora in Denmark and Germany, both in policy circles [1,2,3,4] and in academia [5,6,7,8]. Closely connected are policy debates on new models for consumer-centered electricity markets [9,10,11,12,13,14] and research [15,16,17,18,19] in this field, resulting from the merit-order-effect "missing money problem" on current wholesale electricity markets, as well as the changing regulatory landscapes away from feed-in-tariffs [20,21]. This paper gives a current status on the debates.

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Keywords: electricity market reform, prosumer markets, distribution grid tariffs

Max Fette is a researcher at the Fraunhofer IFAM. He has previously worked as a project engineer and consultant in London carrying out feasibility studies and project implementations for CHP applications. His research work concentrates on the fields of CHP, sector coupling and renewable energy

System friendly operation of sector coupling devices: between welfare requirements and business reality

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Sector coupling technologies are best operated at times when they benefit the electricity system. Examples are heat pumps or CHP-plants that can reduce the residual load in the electricity system. If however the plants are run in a way to maximise the income of the operator, the operation is quite different from the schedule that would be optimal for the system. This is due to current barriers that prevent the system friendly operation or eradicate the economic feasibility of the technology in question altogether. The research project MuSeKo, jointly carried out by the research institutions Fraunhofer IFAM, DLR – Institute of Engineering Thermodynamics and the gwi Institute (Gas and heat Institute) addresses these differences between welfare requirements and business reality by analysing them and proposing measures how a system friendly investment and operation can become attractive for the operator. It is shown, that the plant sizes and operation schedule optimised to minimise the cost for the national economy is quite different from the optimal plant sizes and operation schedule of e.g. an operator of a local heat network (optimised with the energy systems models REMix (DLR) and MuGriFlex (IFAM) respectively). It is shown, that plant sizes and operational schedules can be brought more in line to the requirements of the overall system by considering local electricity markets or by varying the taxes and surcharges on electricity with the electricity prices.

Keywords: Sector coupling, welfare requirement, political economy, business reality, power to heat, heat pump, CHP, plant scheduling, plant operation, market barriers

Dr **Renee Heller** is head lecturer and researcher Sustainable Energy Systems at Amsterdam University of Applied Science. She worked at Ecofys, a consultancy in energy efficiency and sustainable energy. At AUAS she leads projects on heat and solar integration in cities.

Progress towards 4DHC in different national and regional contexts

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Lessons learned on the progress towards 4th generation district heating (4DHC) are presented from 6 pilot implementation projects in the UK, Ireland, Belgium, France, and the Netherlands (HeatNet project). The pilots have implemented the infrastructure for district heating from various (waste) heat and renewable sources to reduce CO2 emissions. With the development of long term road maps, progress is made towards the role out of 4DHC in the regions. The pilots have a different level of experience with district heating and transnational learning is specifically addressed. Purpose of the evaluation of the pilots is to give local authorities insight into barriers and solutions and the way they are closely linked to stakeholders in their geographical, political and cultural context in NWE. To do this, the financial, regulatory and organisational barriers the pilots face and possible solutions that were shared between the pilots are analysed in the context of system innovation. Differences in national and regional contexts have been analysed to be able to generalise solutions to a level they can be used in a different context. We will confront the pilot's development with best and worst practice from literature and score Key Success Factors.

Keywords: 4th generation district heating, project implementation, evaluation, key success factors, lessons learned, financial, regulatory and organisational barriers, regional context

Reinhard Haas is university professor at Energy Economics Group, Institute of Energy Systems and Electric Drives, at Vienna University of Technology in Austria. His current research focus is renewables, sustainable energy systems, energy markets and energy policy strategies.

On the role of storage in smart energy systems

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Larger shares of renewable energy sources are considered as a precondition for heading towards sustainable electricity systems. In recent years electricity generation from variable sources has raised and led to calls for additional storage capacities. To balance electricity supply over time calls for storages has been launched. Storage has played an important role for balancing generation and demand at least to some extent since the beginning of electricity systems with pumped hydro storage This balancing has to be done over short and longer periods e.g. months and year. The core objective of this paper is to investigate the market prospects of different electricity storage options. The major conclusion of our analysis is that with respect to all centralized long-term storage technologies the future perspectives are much less promising than currently indicated in several papers and discussions. It will also become very hard for power-to-gas (PtG) technologies to compete in the electricity markets despite a high technological learning potential. Yet, for hydrogen and methane there are prospects for use in the transport sector. Fuel prices in transport in recent years have rather increased compared to stagnation or decreases in electricity spot market prices. Consequently, and given in addition the lack of environmentally benign fuels for mobility hydrogen and methane from renewable electricity might become an economically alternative for fueling passenger cars.

Keywords: Economics, full-load hours, hydrogen, battery storage, technological learning

Michael Reisenbichler studied mechanical engineering with a focus on energy and process engineering at the TU Graz. Since 2017 he works at AEE INTEC in the field of thermal energy technologies and hybrid systems with a focus on thermal energy storage systems. Projects: EU project “CREATE”, national project “giga_TES”.

Towards large-scale thermal energy storages for renewable district heating systems

Michael Reisenbichler (presenter)[1], Wim van Helden[1], Ingo Leusbrock[1], Patrick Reiter[2], Christoph Muser[3], Gernot Wallner[4], Fabian Ochs[5],
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In order to reach the long-term goal of a 100% renewable energy supply, district heating (DH) systems require large-scale thermal energy storages (TES) to further increase the share of renewable energies and achieve highly flexible DH systems. Compared to currently installed large-scale TES in Germany and mainly in Denmark with volumes up to 200,000 m³, for large DH systems in Austria a tenfold increase in volume is needed. Therefore, within the Austrian flagship project “giga_TES” concepts for seasonal large-scale TES with volumes up to 2,000,000 m³ are developed. Goal: The main goal of the project is the development of different dedicated concepts for large-scale water pit storages that (a) provide more storage capacity, (b) have an increased lifetime, (c) are energetically better, (d) are more cost-efficient and (e) are better integrated in the overall DH system than state-of-the-art solutions. Method: In order to achieve these goals (a) innovative design and construction methods, (b) new materials and components and (c) improved numerical simulation models are developed. Results: So far (a) design boundary conditions for three application scenarios in Austria have been defined, (b) tests on novel polymers and concrete formulations have been performed, (c) construction designs for walls, bottom and lid have been developed and (d) component and system simulations have been conducted. Detailed results of the first 1.5 years of the project can be presented at the conference.

Keywords: large-scale thermal energy storage, water pit storage, seasonal thermal energy storage, numerical simulation, innovative materials, innovative components

Keith O'Donovan has completed a Masters degree in Mechanical Engineering at University College Dublin in 2016. Since then he has been wokring as a scientific researcher and project worker in the field of thermal energy systems as the Institute for Sustainable Technologies in Gleisdorf, Austria.

gigaTES: Giga Scale Pit Storage as essential part of district heating system

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Due to the fluctuating nature of renewable heat sources, thermal energy storage (TES) is a necessary technology needed to bridge the gap between supply and demand in the heating sector. For district heating networks, large-scale TES technologies such as pit and tank storages have proven to be well suited for this. The gigaTES project focuses on the development of storages in the range of 100,000- 2,000,000m3 in storage design, construction, as well as the technical, economic and environmental impact of such storages in DH grids. A significant part of the project involves a detailed simulation study of gigaTES technologies integrated as part of representative case studies in Austria (e.g. Vienna, Salzburg). As Austrian DH grids operate at higher system temperatures, the application of an additional heat source (e.g., absorption or compression heat pumps) before feed-in from the storage into the grid has to be considered and evaluated. The goal of the scenario studies is to optimise the integration and operation of the gigaTES pit storage as element in the overall DH supply mix, preferably at the highest ecological benefit and at the lowest possible cost. Thus, technical, ecological and economic indicators are therefore used to assess the overall system performance. First results and a detailed methodology will be presented as well as an evaluation of gigaTES concepts in the Austrian and Central European context.

Keywords: Giga large thermal energy storage district heating absorption heat pump simulation

Tiziano Gallo Cassarino is a Research Associate in energy system modelling. His main interests include energy demand, weather and behaviour-driven hourly simulations, heat decarbonisation strategies, integrated system spatio-temporal analyses, and control systems.

Designing zero emission, least cost, and high renewable energy systems that optimise storage and interconnections

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In order to reach net zero emissions around 2050, current energy systems must be decarbonised by integrating a range of different options, from renewables to behavioural change. Although 100% renewable energy systems are feasible, climate and weather cause large fluctuations in demands and renewable generation, making the seasonal and in particular the inter-annual match of supply to demand especially challenging.
We developed a bottom-up model for system design, called ESTIMO, which uses multiple years of weather data and social patterns to simulate an integrated energy system at national and international scales, at hourly resolution. The main aim is to find the optimal mix of storage and interconnections for a future highly electrified energy system based on renewables and influenced by climate change. Our model includes several demand sectors as well as the principal renewables and technologies, such as district heating, storage, EVs, and electrofuels. Preliminary results using historical data show that interconnections could theoretically decrease the amount of electricity storage needed annually at the European scale by an average of 61 TWh. Depending on the chosen year, this reduction represents between 25% and 100% of European total storage requirements. Our findings show that new modelling approaches considering the hourly dynamics of integrated systems covering a large geographical scale are crucial to gain insights into and designing optimal future energy systems.

Keywords: European integrated energy system, zero emission scenarios, bottom-up demand modelling, multi-year hourly simulation, storage.

Joseph Maria Jebamalai is working as an innovation engineer at Comsof, Belgium and he is also a PhD fellow at Ghent University, Belgium. He graduated in Sustainable Energy Engineering from KTH, Sweden. His area of interest includes district heating and cooling networks and thermal energy storage.

Influence of centralized and decentralized thermal energy storage on district heating network design: A comparative case study

Joseph Maria Jebamalai (presenter)[1], Kurt Marlein[1], Jelle Laverge[2],
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Future district heating networks have to be flexible enough to absorb the heat load variations and additional heat production variations imposed by increasing intermittent renewable energy sources. Thermal energy storage is a proven, efficient and cost effective technology to provide such flexibility. A centralized hot water storage tank near the source is the most common thermal energy storage configuration in district heating systems today. Though this configuration provides flexibility and reduces peak load capacity, it doesn't impact the network peak transport capacities since the heat still needs to be transported from the source location during peak demand periods. This paper investigates the benefits of placing thermal storage tanks in the distribution networks to decrease the network peak transport capacities and balance the heat loads locally. A building level heat demand data is extracted using the open source street level gas consumption data and appropriate heat demand profiles are chosen based on the building type. Comparative case study is carried out using these input data for centralized and decentralized thermal energy storage configuration with Comsof Heat, an automated district heating routing and planning tool. The effect of both storage configuration on network design and cost is compared and several scenarios (of different building profiles / type mix in a cluster) are explored. Furthermore, the effect of different storage sizes is also investigated.

Keywords: district heating, centralized hot water tank, decentralized thermal energy storage, building heat demand profiles, automated planning tool, storage size.

Tobias Fleiter began work at the Fraunhofer ISI in 2007 and coordinates the business unit for energy demand analysis and forecasts. He studied industrial engineering at the University of Flensburg and obtained his PhD in 2012 at Utrecht University.

Deep decarbonisation of the EU industry - A model-based assessment of alternative pathways

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Industry is responsible for about 20% of EU-wide greenhouse gas emissions. It will have to reduce its emissions to almost zero by 2050 to meet the targets set in the Paris Agreement. This paper assesses alternative decarbonisation pathways for the EU industry sector that aim for 80% and 95% reduction of GHG emissions by 2050 compared to 1990. The pathways are compared with regard to energy carrier mix, technology change, and costs. The method applied builds on a technology-rich bottom-up model that simulates technical change in the EU industry sector on a country level. Results show that 80% reduction is possible via alternative technology pathways but requires technology innovation, i.e. market diffusion of technologies still under development at TRL 5 or higher. Four individual pathways focus on CCS, clean gas, direct electrification and circular economy & bioeconomy. Increasing ambition from 80 to 95% requires CCS for remaining process emissions, synthetic methane for remaining gas demands, some early replacement of plants still under operation, and more ambitious diffusion of process innovations. This increase in ambition is related with substantially higher energy expenditures, mainly driven by the higher demand for synthetic methane, hydrogen and electricity, replacing coal, oil and gas. Accordingly, most scenarios experience a strong increase in electricity demand, which doubles or even triples until 2050.

Keywords: Decarbonisation, industry, steel, cement, chemicals

Amela Ajanovic is associate professor at Energy Economics Group, Institute of Energy Systems and Electric Drives, at the Technical University of Vienna in Austria. Her current research focus is on alternative fuels and alternative automotive technologies.

Prospects for the electrification of passenger cars

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The electrification of mobility is currently seen as one of the key strategies for heading towards a sustainable transport system. Many governments have set goals to increase number of electric vehicles (EVs). Although, different types of electric vehicles are already available in use, there are still three major barriers for their broader market penetration: their high capital costs and shorter driving range in comparison to conventional cars, as well as doubtful environmental benignity. The core objective of this paper is to investigate the future prospects for electrification of mobility from an economic and environmental point-of-view. Our method of approach is based on calculation of total cost of ownership of electric vehicles in comparison to conventional cars and a life-cycle approach to assess the environmental benignity. For the analysis of future market prospects we conducted dynamic economic assessments and scenario developments based on policies implemented and price development, based on technological learning. To harvest the full environmental benefits of EVs a very important aspect is the introduction of CO2-based fuel taxes. This should ensure that there is a fair competition with conventional cars and that the electricity for EVs is generated from renewable energy sources – otherwise total CO2 emissions are likely higher than those of conventional cars. The major uncertainty regarding market prospects of EVs is technological learning.

Keywords: passenger cars, emissions, battery, costs, technological learning

Eliana Lozano is a PhD fellow at the Energy technology department in Aalborg University working in process modeling and design of integrated biorefineries with CCU from aquatic and terrestrial biomass. The PhD is part of H2020's ENSYSTRA project, targeting solutions for integrated energy systems transition.

Electro-HTL biorefinery for the production of advanced liquid biofuels

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The decarbonization of the energy system calls for the interconnection of electricity, heat and transport sectors in an integrated system that takes advantage of renewable, highly available, wind/solar power. Power-to-X technologies are emerging as the most promising solution to provide flexibility in the use of electricity, and among this, Power-to-H_2 is the alternative that is drawing more attention in industry due to the wide range of applications of hydrogen: fuel cells, electrofuels, gas turbines, feedstock in the chemical industry, etc. In the production of sustainable liquid biofuels via hydrothermal liquefaction (HTL), hydrogen is a main resource for biocrude upgrading in order to obtain a marketable product that meets the specifications of commercial gasoline and jet/marine fuels.
HTL has been identified as the most feedstock efficient technology among different biomass conversion pathways such as pyrolysis and Fisher-Tropsh, and has shown promising results at pilot scale on the way to its commercialization. The expected deployment of electrolysis technologies is a scenario that provides an opportunity for exploring HTL as technology that utilizes surplus electricity to produce biofuels, allowing the indirect electrification of the transport sector particularly in the heavy transport segment with higher dependency on fossil fuels. HTL can handle different types of feedstock and organic residues making use of the fixed carbon available in biomass, and in the context of Bio-CCU(S) (bioenergy with carbon capture and utilization (storage)), has the flexibility to be combined with other technologies to offset CO_2 from the atmosphere contributing to climate change mitigation.
In this study, the electro-HTL concept, referred to the use of renewable electricity for biofuels production via HTL, will be studied having as feedstock forestry residues. The process will be modeled in Aspen Plus ® process simulator using different cost scenarios for the electricity supply and carbon market, and having as expected outcome a techno-economic analysis for the estimation of the minimum fuel selling price and a better understanding of the potential of this technology in the context of smart energy systems.

Keywords: biomass, biofuels, hydrothermal liquefaction, Power-to-H2, electro-HTL

Timo Kannengiesser is a PhD student at RWTH Aachen University and works at Forschungszentrum Juelich in the Institute of Electrochemical Process Engineering (IEK-3), Department for Techno-Economic Energy System Analysis. The thesis is carried out in cooperation with the German distribution network operator Westnetz GmbH. He received his Master from RWTH Aachen University in Sustainable Energy Supply.

Design and Evaluation of Flexible Sector-coupling Pathways in Future Urban Energy Supply Systems

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To achieve greenhouse gas (GHG) emission reductions in urban districts, a transformation of urban energy systems towards high shares of renewable energy in combination with efficiency measures on building level is required. In this context, flexible sector-coupling options, integrated in a smart microgrid, show a high potential to support the transformation. Within this study, a typical urban district consisting of 18 multifamily houses in Germany is investigated to analyze the effects of different refurbishment strategies as well as the integration of battery electric vehicles on the energy supply system. Different urban energy system transformation pathways are considered and compared to each other in terms of cost-efficiency and their ability to meet also future GHG reduction targets with the pathway specific technology portfolio. A Mixed-Integer Linear Program is used to determine the cost optimal design and operation of the different energy supply pathways. As a result, effects on the district energy supply structure e.g. regarding natural gas demand and electricity demand from the grid under the consideration of local self-consumption can be evaluated. Another effect which is analyzed is the change of the pathway specific transformer load, e.g. due to local electricity production inside the district on the one side and the electrification of the heating supply systems and the integration of battery electric vehicles on the other side.

Keywords: Flexible sector-coupling, Pathway analysis, Design and operation optimization, Urban district energy systems

Elisa Guelpa is an assistant professor working on large scale energy system modelling. The main topic she is working on is district heating (DH). Among the issues analyzed concerning DH are peak shaving, optimal network expansion, failure management, network modelling and demand side management.

Integration of power to heat technology in thermal networks

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Integration of different energy vectors, i.e. electricity, gas and heat, offers a great potential for better managing energy sources with lower impacts and costs. In a framework of increasing exploitation of excess heat from industries and a wide range of renewable technologies, the possibility of jointly managing different types of energy networks is becoming appealing. This makes the conception of the various energy infrastructure (networks, storages and energy vectors conversion systems) more and more connected. Among the opportunities offered by energy vectors conversion, one of the more interesting consists in the conversion of electricity into heat. This chance becomes much more appealing during the electricity production peaks, especially when large renewable capacity is installed and production fluctuations are not negligible. In these cases, use of heat pumps for the conversion of electricity into thermal energy (heat or cold depending on the season) can enhance the exploitation of excess electricity. With this aims, integration of heat pumps and thermal network is not straightforward, since it depends on the network topology and demand characteristics. Here a model is presented that define the best heat pump installation characteristics, in order to wisely exploit electricity and thermal network connection, in district contexts. The aim of the model consists in estimating a solution that guarantee the best electricity exploitation when converted into thermal energy.

Keywords: heat pumps, smart energy system, sustainability, smart energy systems, district heating

Peter Sorknæs is part of the Sustainable Energy Planning Research Group at Aalborg University, where he works with energy markets for energy systems based on variable renewable electricity and hourly cross-sectoral energy system modelling of energy systems of different geographical scales.

Livø – A micro-scale smart energy system

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Energy systems worldwide are transitioning towards increasing levels of renewable energy. Transitioning geographical islands to increasing levels of renewable energy has been the subject of research for many years. This presentation will show how a micro-scale off-grid island, where there are significant planning restrictions on the physical environment, can integrate locally available renewable energy sources in all energy sectors, so that the island's energy demands are mainly supplied by these sources. The case island is the Danish island of Livø with an area of 320 hectares and 10 permanent residents. During the summer period around 25,000-30,000 tourists visit Livø. Two energy grids exist on Livø, being a district heating system with a yearly demand incl. grid loss of about 0.43 GWh and an off-grid electricity system with a yearly demand of about 0.17 GWh. Besides the energy grids, Livø also has energy demands for equipment used for forestry and agriculture, and a ferry that transports goods and people to and from the island. Currently, the energy demands are primarily meet by utilizing imported fossil fuels; however, it is the long-term goal of the island's owner, the Danish Nature Agency, to be able meet all energy demands on the island with locally available renewable energy sources. Livø is under protected status, and as such, the possibility to build energy conversion units, such as wind turbines, is extremely limited.

Keywords: Smart energy system, geographical island, self-sufficient, renewable energy, energy system analysis

Raffaele De Iulio

Analysis of Smart Energy System approach in local Alpine regions - a case study in Northern Italy

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The increase of climate change effects is becoming a major challenge to be urgently tackled with a combination of measures, particularly effective when deployed in a Smart Energy System context, when positive interactions among sectors can be exploited to meet the challenging targets that are being set at different governance levels. Local energy planning strategies, relying on multi-level and integrated approaches, are needed to ensure that optimal solutions are developed according to specific resources and requirements of each region. With the help of EnergyPLAN software, this paper explores and compares possible future solutions for the decarbonization of an Alpine region in the North-East of Italy. Options for a sustainable and optimized exploitation of local renewable resources are analyzed through possible synergic sector couplings, electrification of the heating sector, district heating, space heating and hot water production. Results strongly highlight the necessity of a cross-sectoral approach based on energy efficiency actions showing a significant reduction of CO2 emissions when integrated measures based on renewables are extended towards other sectors currently heavily dependent on fossil fuels. Due to the similarities with other regions across the Alps, the outcomes of this study may be replicated to neighboring countries accounting for their local features.

Keywords: Local Energy Planning, Smart Energy Systems, Renewable Energy Sources, Energy Efficiency

Els van der Roest is active as an Energy and Water researcher at KWR and has a background in Chemistry and Energy Science. Her interests focus on the interface between energy and water because these two areas are becoming increasingly interdependent in the energy transition.

Power to X: a novel, reliable, affordable and clean energy and water system for a neighbourhood

Els van der Roest (presenter)[1], *Laura Snip*[1], *Theo Fens*[2], *Ad van Wijk*[2]
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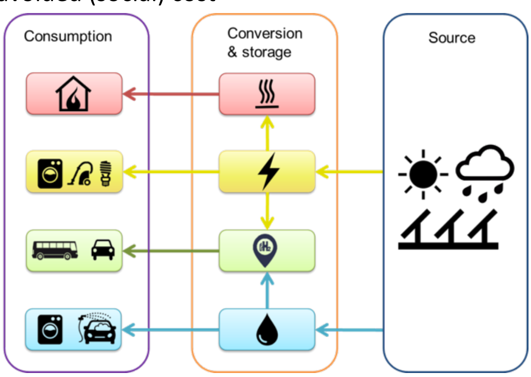
Our fossil energy system is changing into a renewable energy system and in this process, we need to ensure that the energy system remains reliable, affordable and clean. An integrated system approach is crucial and should contain different forms of energy conversion and storage, in order to deal with the intermittent nature of renewable energy, as well as the temporal and spatial mismatch of supply and demand of different utilities. The concept we would like to introduce is a version of 'Power-to-X'; it comprises the conversion and management of renewable power, heat and hydrogen, rainwater collection, and (seasonal) storage and use in a neighbourhood. Heat is stored at a temperature of 40-60˚C in aquifers during summer to fulfil heating demand during winter. Hydrogen fulfils the mobility demand within the neighbourhood. Rainwater capture can be a source for hydrogen production and fulfils part of the neighbourhoods' water demand. A dynamic simulation model was developed to determine the energy and water balance and perform economic analysis for various scenarios, including an analysis of the avoided (social) costs such as electricity grid reinforcement. The presentation will include the results of a two-year long research project on the Power-to-X concept on a case in Nieuwegein (the Netherlands).
Keywords: Renewable energy, water, system integration, urban energy , energy conversion, energy storage, hydrogen, aquifer thermal energy storage (ATES), heat storage, hydrogen, avoided (social) cost



Costanza Saletti is a PhD fellow in Industrial Engineering at the Department of Engineering and Architecture of the University of Parma. Her research interests are related to the simulation, optimization and advanced control of complex energy systems and district heating and cooling networks.

A smart controller for small-scale district heating and cooling networks: development and testing

Costanza Saletti (presenter)[1], Andrea De Lorenzi[2], Agostino Gambarotta[3], Mirko Morini[4], Michele Rossi[5]
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District heating and cooling networks are flexible and allow thermal energy to be distributed to the end-users more efficiently compared to single boilers. However, smart control approaches are required to further increase the efficiency and flexibility, and to integrate renewable energy sources.
In this work, a Model Predictive Controller is prototyped. It operates the system by predicting its behavior in a future time horizon through a physics-based model and by solving the resulting optimization problem through a novel Dynamic Programming algorithm.
The development and testing methodology is based on a Model-in-the-Loop simulation platform, which allows different controllers to be tested in different conditions without affecting the real network operation. In the platform, a library of dynamic models of energy system components, developed in Matlab®/Simulink®, is used to build the model of the network, which is controlled by a model of the controller. A multi-agent strategy is adopted to split the network into smaller subsystems (buildings) each solved by a representative agent.
The preliminary results of the analysis are compared with those obtained from a conventional control strategy based on time-scheduling and show a 5 % to 12 % global energy saving depending on the season. Lastly, the controller has been prototyped and an on-field test has been successfully performed in a branch of the district heating network of the campus of the University of Parma.

Keywords: smart control; Model Predictive Control; district heating and cooling networks; optimization; Model-in-the-Loop; simulation platform; energy efficiency; flexibility; optimal management; testing

After **Matteo Giacomo Prina** graduated at Politecnico di Milano in sustainability and energy management, he has worked at EURAC research and has started a PhD program in Energy engineering at Politecnico di Milano. The title of his PhD project is renewable energy high penetration scenarios using bottom-up modelling.

EPLANopt optimization model based on EnergyPLAN applied at regional level: the future competition on excess electricity production from renewables

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To face environmental and energy security issues, planning an energy system with high penetration of renewables is becoming increasingly important. The EPLANopt model couples a multi-objective evolutionary algorithm to EnergyPLAN simulation software to study the future best energy mix. In this study, EPLANopt is applied to the case study of Niederosterreich, an Austrian region, to inspect the best configurations of the energy system at 2050. This model is used to inspect the competition between different renewable energy integration options. Storage systems, power to gas, power to heat or power to mobility are all integration options taken into account to study their competition in presence of electricity excess from renewables. The results show that in order to decarbonize the energy system the increase of installed power of renewables is not enough to reach the CO2 reduction objective. Integration methods like the already mentioned storage systems, power to gas, power to heat or power to mobility become relevant. In particular the results show a deep energy efficiency refurbishment coupled to power to heat through heat pumps. Power to gas presents a relevant role in the integration of the excess of electricity from renewables. However, at the increase of electric mobility penetration the available excess of electricity is reduced and the deployment of power to gas decreases.

Keywords: Energy scenarios, Photovoltaics, EnergyPLAN, Multi-objective optimization, Emissions, Cost-optimality

Henrik Madsen became PhD in Statistics at DTU in 1986, and Professor in Statistics in 1999. His main research includes modelling, prediction, and control with applications related to smart grids and district heating. He is appointed Knight of the Order of Dannebrog by Her Majesty the Queen of Denmark.

Perspective in Using Meter Data for Temperature Optimization

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More data is now available in the district heating sector due to EU rules requirements that almost all household should have smart meters in 2020. The smart meters give the opportunity for both end-users and DH company to observer the end-user consumption and learn their behavior. Along with the digitization, new houses are also becoming more energy efficient thus they can be supplied with lower supply temperature without noticing any changes. District heating is becoming smarter and they can utilize these opportunities to create network with different temperature zones to achieve more energy efficient systems. Data-intelligent methods will make it possible to operate different temperature zones by using statistical methods like semi-physical models (grey-box modeling) based on the knowledge from the end-user with temperature mixture and additional pressure pumps inside the grid. Creating a new temperature optimization for the district heating using the methods above will result in savings as the supply temperature will be lowered and the flow will be controlled to supply the same energy demand. New study by DAMVAD Analytics about the huge potential of savings when using temperature optimization in DH shows the savings in Denmark will be between 240 to 790 MDKK per year however the study was only done for current temperature optimization. Only time will tell how much the additional savings will by including information from the end-user, or the Temperature Optimization v.4.0

Keywords: Data-Intelligence, Low-Temperature, Smart Meters, Multiple Temperature Zones, Smart Cities Accelerator

Igor Krupenski is the head of heat and gas supply systems designing company and lector in the Department of Energy Technology, Tallinn University of Technology(TalTech). He defended his PhD in TalTech 2010. He is involved in the district heating and gas development projects in Estonia and Europe.

Low temperature district heating network energy cascade connection to the return line of a high-temperature district heating network

Igor Krupenski (presenter) [1], *Anna Volkova*[2], *Aleksandr Hlebnikov*[3], *Eduard Latõšov*[4], *Aleksandr Ledvanov*[1], *Vladislav Mašatin*[3],
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Low-temperature district heating (LTDH) can be considered to be the most profitable heat supply option for new and renovated energy-efficient urban buildings. In case this area is located in the district heating region where the heat is supplied by a well-established high-temperature district heating (HTDH) system, one of the possibilities is to utilise the heat from the network return line to supply the LTDH network. The goal of the research is to evaluate the technical and economic feasibility of integrating the energy cascade LTDH network into the existing large-scale HTDH system. The return water temperature of the HTDH return line is, on average, 40-50°C, depending on the system; LTDH maximum supply temperature can reach up to 65°C. Additional energy is required to raise the HTDH heating media return temperature to the LTDH level. Two direct connection options are compared: a mixing shunt and 3-pipe connection shunt. Technical and economic aspects of the abovementioned options are analysed, including heat and electricity consumption, water flow rate, pressure, as well as additional investments and heating costs. Particular emphasis is put on assessing the decrease in the HTDH return temperature caused by the integration of the LTDH network and its impact on HTDH operational efficiency, including the reduction of heat transfer energy losses, increase in heat and power generation efficiency at CHP plants, and flue gas condenser efficiency.

Keywords: energy cascade, low temperature district heating, exergy

Phil Jones is an Independent Energy Consultant with 40 years in the experience in the built environment. Specialist in district heating, heat pumps and CHP. Previous Chair of CIBSE CHP & District Heating Group.

5th GENERATION HEAT NETWORKS - A Roadmap to decarbonising heat using ultra low temperature networks

Phil Jones (presenter)[1], *Chris Dunham*[2], *Justin Etherington*[3]
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5th generation ultra-low temperature district heating/cooling (5DHC) networks, using decentralised heat pumps, present a major opportunity to decarbonise the way we supply buildings. Much of UK DH is 2nd to 3rd generation district heating. More innovative schemes are coming forward based on 4DHC (~50/30°C), and even more innovative 5th generation ultra-low temperature systems. 5DHC uses 2-pipe warm/cool headers acting as a source/sink for distributed heat pumps to provide both heating and cooling from the same system. Buildings can then become 'prosumers' to share heating and cooling across a network. A wider range of energy sources can then be harnessed to reduce fossil fuel usage in areas of highest energy density. This paper sets out work under the HeatNet EU Interreg project to create a transition pathway for low carbon 5DHC to supply residential and commercial buildings. The work has identified; what do we mean by 5DHC? how would we define it? and what would it actually look like? The ultimate aim being the development of a roadmap to encourage more 4DHC and 5DHC systems. This paper sets out:

- Definitions for 4th and 5th generation heat networks
- Practical shape/topology, temperatures, plant etc
- Advantages and disadvantages
- Where to apply 4DHC and 5DHC
- Potential economics and benefits to developers/operators This paper shows that 5DHC is a practical solution to decarbonise district heating and cooling across the UK.

Keywords: 5th generation, District heating, heat networks, low temperature heating, heat pumps

Sabine Jansen works as assistant professor at the faculty of Architecture at Delft University of Technology, focussing on innovative, sustainable urban energy systems. She wrote her PhD thesis on the application of the exergy concept to energy systems in the built environment.

Designing smart low temperature heat grids based on spatial allocation of demands and sources

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Low temperature heat grids have great potential to realize sustainable heat supply systems, since many heat sources below 35°C are available in urban areas. These include waste water, surface water, cooling processes, small industries and solar thermal energy. On the demand side usually higher temperatures are required which means the temperature needs to be upgraded. Different solutions can be designed depending on where this temperature upgrade takes place. This paper presents ongoing research of the 'Cool Heat Grid' (KoWaNet) project, showing an overview of the different configurations of low temperature heat grids and low temperature heat sources, as well as an approach on how to design the most suitable system given the available sources and demands. The first step is to estimate the monthly demand profiles and required power. The second step is to explore solutions in terms of storage and renewable supply. After that, the sources and demands are visualised in a spatial scheme. This way various configurations of the thermal grids can be designed, based on the spatial allocation and temperature levels of demands and sources. The spatial levels distinguished are: unit (one dwelling or non-residential unit), multifamily or larger building level, urban block level, neighbourhood and city level. The configurations can be evaluated in terms of energy performance, costs, governance and spatial needs. The approach will be demonstrated with two case studies in the Netherlands.

Keywords: Smart thermal grids, neighbourhood energy system, low temperature heat grid, temperature levels, matching demand and supply, distributed energy sytems

Tobias Sommer is a physicist with a PhD from ETH Zurich, Switzerland. He is interested in physical processes in fluids, such as mixing in lakes, hydraulics in thermal networks and wind-wave interactions in the ocean during windsurfing.

The reservoir low temperature network: A new topology for simultaneous heating and cooling

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District cooling becomes more and more important with increasing air temperatures due to climate change, in particular in urban areas. The waste heat generated by cooling is ideally recycled for heating and domestic hot water, either immediately or time delayed using seasonal storages. Here, we present a new network topology, the reservoir low temperature network, that provides optimal mutual benefit for simultaneous heating and cooling and is, at the same time, robust in operation, flexible toward network expansion and more cost effective compared to other low temperature network topologies. We define low temperature networks as networks below 20 °C. In such systems, heat pumps supply the warm water for heating, whereas heat exchangers supply direct cooling. In the reservoir low temperature network, water continuously circulates in a ring line, which represents the “reservoir”. Clients withdraw water from this line, transfer heat and reinject the water into the same line. Clients can be residential buildings, industrial facilities, seasonal storages or even entire district heating or cooling networks. In this work, we present a virtual, but realistic district with yearly heating and cooling demands and analyse three low temperature network topologies with respect to the energy consumption, investment costs and robustness in operation. We further present a general method to estimate savings at planning stage based on expected yearly demand profiles.

Keywords: district heating networks; district cooling networks; Modelica/Dymola Simulations, waste heat

Brian Elmegaard is professor in the field of thermal energy at DTU Department of Mechanical Engineering. He holds a doctoral degree from the same institution. His research focus is optimization of large-scale heat pumps for integration in future district heating and industrial energy systems.

Accurate modeling of heat pumps and excess heat sources in energy system models

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Energy system models are used for developing strategies and for analyzing future development of the energy system. In Denmark these tools include Balmorel, TIMES-DK, EnergyPLAN, which are used by different stakeholders. Accordingly, the tools have significant impact on political decisions and investment. The accuracy of the models is thus of high importance. The models rely heavily on estimates for representating plants, and actually the models all use the same data source, i.e., the Technology data catalogue published by the Danish Energy Agency. Since the models use the same data source, it is even more important that this source has the highest possible reliability; and that the use of its data is correct. For heat pumps using excess heat as low temperature source, the performance is related to the maximum possible utilization in terms of Coefficient of Performance, COP, based on the Lorenz cycle limit. This should use the right temperature values in the calculation of COP and capacity, based on the temperature difference of the cooling the source, not the temperature of the excess heat at the point of emission, to actually obtain heat from the heat pump. This will also determine the actual capacity of the heat pump. The presentation will discuss the correct representation of heat pump COP and capacity and the impact on investment based on these. Further the impact on energy system simulation will be presented based on modeling in TIMES-DK for the period 2020-2050.

Keywords: Heat pumps, Excess heat, Energy System Models

Francesco Neirotti is currently a PhD student in Energy Engineering at Politecnico di Torino. His research activities are focused on different decarbonization strategies in the heating and cooling sector, including heat pumps and low-temperature district heating.

Comparison of electricity mixes in generation and demand: the case of heat pumps in Alpine regions

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Energy systems are facing a strong transition towards challenging decarbonization targets to face climate change. Following the Smart Energy System perspective, a strong cooperation across different sectors is necessary to reach more effective and sustainable results. The strong development of renewable energy sources in the power sector is currently providing an interesting solution to provide low-carbon electricity generation. Thus, these technologies could be used to decarbonize other sectors increasing by increasing the electricity penetration, especially in transport and building heating. However, a large share of renewables is produced from non-dispatchable sources, mainly wind and solar PV, and their daily and seasonal variability needs to be matched with the demand profiles of those sectors, unless large electricity storage capacity is deployed. This research work is focusing on this specific issue, with the aim of evaluating the average generation mix of the electricity consumption of heat pumps in comparison with the annual mix of the power system, based on hourly demand and generation profiles. To increase the significance of the results, different countries across the Alps have been analyzed and compared. The results highlight the potential mismatch between electricity demand and renewable generation in some countries, resulting in the need of future adoption of storage systems or alternative solutions to support an effective low-carbon heat pump deployment.

Keywords: Heat pumps, electricity mix, renewables, electricity profiles

Jann Launer is a researcher at Reiner Lemoine Institut, Berlin. A physicist by training, he is passionate about using data analysis and modeling to investigate pathways in the energy transition. His current work is in the advancement of models for heating systems and model comparison experiments.

Open models of optimal system operation in central vs. decentral heat supply

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District heating plays an important role in decarbonized heat supply. Large-scale technologies, cogeneration and storage offer higher efficiency, flexibility and lower specific costs. Given sufficient heat demand density, these benefits prevail over distribution losses and costs. However, its realization is complicated by various constraints. Renewable heat sources must replace carbon-intense technologies in existing systems. Volatile electricity markets call for flexibility. On the other hand, heat demands may decrease in the future due to building retrofit and population decline. Optimization models incorporate all relevant constraints and help to identify favorable solutions. To base decisions on firm ground, transparent and robust analysis is essential. We apply linear optimization in a scenario-based case study of a district heating system. The system is composed of a CHP, resistive heaters or large-scale heat pumps respectively, a peak load boiler, thermal energy storage and the district heating network. We determine cost-optimal hourly operation and evaluate it based on emissions and overall costs. Uncertainty and sensitivity analysis convey the robustness of results. The model is implemented in Python and uses the open energy modeling framework oemof. For transparency and reproducibility, we publish the code and data under an open license. The work demonstrates the use of an open science approach as a basis to help include more renewable heat in district heating.

Keywords: District heating network, Power-to-Heat, Large-scale heat pumps, Flexibility, Linear optimization, Sensitivity analysis, Open Science

Ashish Chawla is a master student from the Technical University of Denmark in Sustainable Energy Engineering (Thermal). His master thesis was Energy Optimisation at an oil refinery in Denmark. His background is in chemical engineering and works towards achieving sustainability in industries.

A practical approach to performing Pinch Analysis followed by Heat Exchanger Network retrofit of an oil refinery

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Energy efficiency in oil refineries is an effective measure to reduce greenhouse gas emissions and energy use. Research has focused on the application of heat integration in industries; however, little emphasis is given to the practical use of unreliable/unavailable data from the industries and its integration with the energy system.
The study used temperature correction factors to produce a balanced heat exchanger network and study the use of excess heat for district heating. It also validated the proposed retrofits by analysing the impact of the retrofit on the area of all heat exchangers in the network. Finally, it evaluates the robustness of the results due to input temperatures and mass flow rates.
A Pinch analysis of a section of plant was done before optimising the heat network. The thermodynamic ideal heating and cooling energy targets of the heat network were 74 MW, which exceeded the actual energy use by 20%. The pinch point was 254.7 °C at a global minimum temperature of 30 °C. Retrofits were proposed to reduce this inefficiency and amount of excess heat for district heating was quantified.
The retrofits were simulated in PRO/II software to analyse its impact on the entire heat network. The best-case scenario had a net present value of 51 MDKK over 15 years, with avoided emissions equal to 11.4 KTonsCO2 eq./year. Uncertainty analysis, done through Monte Carlo simulation, found that the Energy Targets were quite robust against the defined uncertainties.

Keywords: Pinch Analysis, HEN retrofit, Data Extraction & Reconciliation, Retrofit Validation, Economic Analysis, Uncertainty of Input Data, Unisim ExchangerNet, PRO/II

Tom Prinzie is a technical Manager of Van Marcke NV. Head of the Van Marcke Engineering Department. Project leader of the Knowledge based Sale Strategy. Expert on District Heating, Renewable Energy and HVAC dimensioning. Member of the board of Warmtenetwerk Vlaanderen Association (District Heating Flemish Association).

Floating Solar Photovoltaic System: Part 2 - Insight on the feasibility and optimal design considering ecosystem thermodynamics

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This paper is the second part of a study regarding insight on the feasibility and optimal design considering ecosystem thermodynamics of Floating Photovoltaic System (FPV). The first part was "Floating Solar Photovoltaic System: Part 1- Insight on the environmental assessment considering ecosystem thermodynamics". In the previous paper a theoretical framework for assessing the water bodies use impact regarding the effect in FPV system considering a cost/benefit trade-off of the ecosystems' capacity to transform solar exergy into ecosystem services was presented. In this second part, a detailed formalization of optimal design of FPV considering ecosystem thermodynamics and the associated challenges are given. Moreover, the study considers that the housing density of Flanders, Belgium, (including roads, parking and public areas) represents 47% of the available surface area, which make a challenge to find suitable space for renewable energy installations in this region. Furthermore, Belgium took the commitment to reduce 15% CO2 by 2020 compared to 2005. In order to achieve this target, the Flanders region must guarantee a share of renewable energy source which at least can be translated into the substitution of 2.156 Mton equivalent fuel. Previous studies have shown how FPV systems increase the photovoltaic efficiency meanwhile reduce the water evaporation and/ or preventing pollution. The implementation of FPV system have been also associated with a higher power output due to elements such as: natural cooling of the panels, reflections of light on the water surface and higher radiation above water compared to landscape areas. However, as was pointed out in part 1 of this study, at local ecosystem level some disadvantages can be found. For instance, it is possible that due to the less sunlight and temperature of the water, there are certain negative ecological effects that appear. In this study we apply the methodology described in part 1 which considers ecological factors within the conventional models to achieve an optimal design of the floating photovoltaic system. The method is applied to three different study cases regarding their size and hydrological characteristics. The selected study cases are: a small pond of 600 m², an artificial water reservoir of 1800 m² and the third one a natural lake with 50000 m². The first two cases are in the Belgian cold weather condition, while the third water body is in a mountain at a subtropical and humidity weather condition. Since the methodology includes the influence of the water evaporation, the species richness, the surface temperature of ecosystems and the reduction or not of CO2 emission to the atmosphere a more holistic valuation for decision making is achieved. Hence, this paper describes the implementation of a new FPV design approach, the challenges faced during modelling and the solutions applied to the challenges. Furthermore, the analysis aims to point out the potential of integrating ecosystem dynamics to conventional sizing method as an effective solution to achieve complementarity of multiple stakeholders' motivation and priorities towards increases sustainability in the energy sector. Results demonstrates that by searching the optimal design considering ecosystem thermodynamics the robustness of the FPV system increases.

Keywords: Floating Solar Photovoltaic; Ecosystem thermodynamics; Environmental assessment; Sustainability

Prof. **Philipp Schütz** studied physics at ETH Zurich with special qualifications in theoretical physics. He received his PHD in 2009 at the Biochemical Institute of the University of Zurich. His main competences are physical modelling and simulations, high performance computing and Energy system modelling.

Automated building modelling based on Smart Meter Monitoring Data

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In European households, 79 % of the energy is consumed for space heating and cooling. The remote detection of possible retrofitting targets can help to increase the renovation rate and hence contribute to the realization of the 2000 W society. This contribution presents a method to characterise buildings using smart meter monitoring data based on a simplified physical simulation model. The method has been successfully applied on simulation and real-world smart meter monitoring data. The annual space energy demand was excellently reproduced with a deviation of less than 1 % and 8 % for simulation and real-world buildings, respectively. The recovered relevant building parameters deviate less than 1% for the reference case. Future tests will clarify how accurately the reproduction method works on a large data set of Swiss buildings. Nonetheless, the already successful application of the algorithm on in-silico and real-world data monitoring data indicates the vast potential of this automated modelling technique on heat load prediction and energy-efficient operation of buildings.

Keywords: energy efficiency, heat load prediction, smart meter monitoring data

Hagen Braas received his Master's degree in renewable energy and energy efficiency in 2017. As a PhD cancidade at the Institute of Thermal Engineering at the Kassel University, Germany, he focuses on dynamic simulation of district heating systems.

Generating DHW load profiles of buildings with realistic simultaneity for DH system simulations using DHWcalc and TRNSYS

Hagen Braas (presenter), *Ulrike Jordan, Kassel University, Isabelle Best, Janybek Orozaliev, Klaus Vajen,*
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An integral part of simulation-based studies on district heating (DH) systems is the realistic quantification of heat load profiles, which mainly consist of space heating and domestic hot water (DHW) demand, on the building level as well as for whole districts. Realistic load profiles for single buildings must be generated, which result in realistic simultaneity when aggregated for whole districts. DHWcalc is a free-access tool for generating DHW draw-off profiles for buildings based on probability distributions and boundary conditions given by the user, initially released in 2005 by the Department of Solar and System Engineering of Kassel University [1]. With recent updates the functionality of DHWcalc was expanded, so that series of profiles can be generated with the aforementioned requirements for simultaneity. In this work series of hot water draw-off profiles were generated with DHWcalc and the heat load was calculated in TRNSYS models of DH substations with instanta-neous water heaters. The simultaneity of generated DHW load profiles was compared with literature values. Furthermore, the influence of profile generation parameters, like the probability distribution of draw-offs, on the simultaneity was examined. [1] Jordan, U.; Vajen, K., 2005: DHWcalc: Program to Generate Domestic Hot Wa-ter Profiles with Statistical Means for User Defined Conditions. In: ISES Pro-ceedings Solar World Congress, 8.-12.8.2005, Orlando

Keywords: domestic hot water; simultaneity; district heating; simulation; heat load;

Martin Heine Kristensen is working as a postdoc and business developer at the Dept. of District Heating, Aarhus Municipality, in collaboration with Aarhus University. His research involves identifying consumption patterns and developing methods to model citywide DH heat loads using smart meter data.

Citywide hourly dynamic heat load forecasts using building archetype modelling

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Being able to accurately predict the dynamic heat load of district heating (DH) systems is vital for a successful planning of forthcoming DH production needs, as well as for analysing the long-term effects of future energy efficiency upgrades and interventions in the building stock. To do so, DH suppliers need models to accurately simulate the future heat load of their networks. In this study, we propose a methodology to model the hourly end-use heating energy demand in DH networks. The framework is based on a calibration of stochastic energy models of selected building archetypes that together represent the diversity of the building stock. Building-specific data from a publicly available building register in combination with smart meter DH readings and historical weather data make up the only source of information in the calibration. We demonstrate the methodology's application on the residential building stock of single-family houses (SFH) in Aarhus, Denmark, to calibrate nine stochastic SFH archetype models using DH smart meter consumption data from 2017. After a rigorous validation of the individual archetype models' capability to predict the DH energy demand of new unseen buildings belonging to the archetypes, they are used to populate a combined building energy model representing all DH-supplied SFH's in Aarhus. We test the citywide performance of the model across the entire year of 2018 by matching hourly simulations against actual data from the buildings.

Keywords: district heating; smart meter data, hourly time series; building energy modelling; archetypes; single-family houses; citywide;

Michele Tunzi is a postdoc researcher at DTU. He is part of the new IEA Annex TS2 'Implementation of low temperature district heating systems'. His research interests are related to district heating technology, optimal control of heating systems and modelling of buildings and smart energy systems

Smart double loop network for ultra-low temperature district heating in low-heat density areas

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District heating (DH) is a cost-effective method of supplying heat from aggregated energy sources and is currently facing the technological transition towards the next generation, characterised by low operating temperatures. However, the expected cities' expansion in the next years and the improved building performances will question the competitiveness of conventional DH in particular for new/low-heat density areas. This study investigated a double loop network operated with ultra-low supply/return temperatures of 35-45/25 °C as a novel solution for such areas. An electrically heated insulated micro tank is proposed as supplementary heating solution to meet the comfort and hygiene requirements for DHW; whereas, well-operated and controlled space heating systems can ensure the indoor comfort during the entire annual operation with ultra-low temperatures. The possibility to circulate the supply water in the loop network and the use of the micro tank in the primary side are the proposed technical solutions to remove the necessity of having by-pass flows in the service pipes during no-loads periods in summer operations. The results show improved average return temperatures and low distribution heat losses. These offset the additional electricity consumption for the DHW preparation and the micro tank heat losses, highlighting the potentials of ultra-low temperature heat networks to sustain the competitiveness of DH technology for new urban areas in the future energy market.

Keywords: loop network; ultra-low temperature district heating; domestic hot water

Pierre JC Vogler-Finck is a research and development scientist at Neogrid working on model based control and data analytics. His background is in energy systems, buildings and control, with an industrial Ph.D. at Aalborg University. He has been involved in a variety of danish and international research projects.

Data-driven control for efficient and flexible energy use at building level – field investigations in Denmark

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Buildings account for more than a third of energy consumption and greenhouse gas emissions. More than half of this consumption is for heating of space and water, which makes it a key segment to consider for meeting energy and environmental targets. In this heating segment, two essential aspects are energy efficiency and flexibility, ensuring that buildings use only the energy they need and at the times when it is most appropriate for the energy system. A commercial central heating controller for buildings was developed, using data collected within the building with the possibility of using signals from the energy system side. This control relies on data-driven models and optimisation methods to ensure optimised consumption of heating of space and water in an efficient and flexible manner. Additionally, data analytics provide building users with reports allowing performance tracking. The control was tested in more than 100 buildings across Denmark, from large residential buildings to houses, institutions and commercial buildings, heated by district heating or heat pumps. Results show a reduction in energy use from reduced losses and unnecessary heating in the buildings compared to previous controllers. Moreover, the control also provided improved substation cooling in some buildings supplied by district heating.

Keywords: Control technology ; monitoring ; performance tracking ; data analytics ; energy flexibility ; energy efficiency ; building heating operation

Andra Blumberga's focus is energy efficiency of historic buildings and state-of-art building energy efficiency technologies. She has been involved in many international projects and is author of 92 publications in peer-reviewed international journals and conference proceedings available on SCOPUS (H-index 12).

Smart Urban Regeneration in Transition to Positive Energy Block

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The latest trends in urban planning and energy systems are "Positive Energy Blocks that consist of several buildings that actively manage their energy consumption and the energy flow between them and the wider energy system. PEBs have an annual positive energy balance and make optimal use of advanced materials, local RES, local storage, smart energy grids, demand-response, cutting edge energy management, user involvement and ICT". The EU SET-Plan aims to reduce GHG emissions accelerating the deployment of low-carbon technologies and specifically addresses smart cities and communities as the target group. The paper presents conception of transition to Positive Energy Block based on the case study of selected Riga downtown block, incl. thermal envelope energy efficiency; building services energy efficiency; energy flow and energy exchange in demand – response system within the block; energy savings using ICT; small-scale local RES and energy storage to cover the energy demand while complimenting the wider energy system (smart grid). In future PEB`s could be aggregated into Positive Energy Districts thus substantially reducing energy consumption in cities. Energy communities will have significant impact to DH and electricity supply systems. The main goal of this interdisciplinary research is to evaluate the impact of PEB to 4th generation district heating and cooling systems.

Keywords: Smart Energy Systems, information and communications technology, building energy efficiency, smart urban regeneration, energy community, prosumers, RES, energy storage, Positive Energy Block

PhD. **Alfred Heller** was former Assoc. Prof. at the Technical University of Denmark and Vice Center Leader of the CITIES project, that aimed at Smart Energy Systems in Cities. Experiences from these activities are brought into the HEATman project, where the commercial implementation is in focus.

HEAT 4.0 – Digitally supported Smart District Heating

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HEAT 4.0 – Digitally supported Smart District Heating is an Innovation Fund Denmark granted project, J.no. 8090-00046A, with a budget of 36 mil. DKK and runs over 3 years. The project is the largest of actual research and innovation activities with the goal to develop the common platform, HEATman, that was presented in the last year 4DH conference by Heller et al. (2018). In the first year of the project, the overall IT infrastructure is built up and applied to collect a number of baselines are established at three partner district heating. During the project, results will be compared to these baselines to proof documented improvements of the HEATman impacts on the energy performance aiming at a efficiency improvement of 2-4% after having optimized to the state of art. HEATman is also an Innovation Hub for district heating, enabling a smooth and efficient entry for innovative companies into a well-established consortium. The IT platform for HEATman is based on experiences during years, Liu et al. (2017) and will be commercialised to meet the demand of the sector.

References: Heller, A., Aaen, R. and Schmidt, L.M. (2018) HEATman, next generation District Heating concept, 4th international conference on Smart Energy Systems and 4th generation District Heating. Liu, X., Heller, A., & Nielsen, P. S. (2017). CITIESData: a smart city data management framework. Knowledge and Information Systems, 53(3), 699-722. DOI: 10.1007/s10115-017-1051-3.

Keywords: district heating, whole system solution, cross-system advanced control

Basak Falay is researcher at AEE INTEC since 2018. She holds a MSc in Sustainable Energy Systems at the University of Applied Sciences Upper Austria. Her research areas are simulation of district heating networks based on future scenarios and developing automated tools that link different software.

Enabling large-scale dynamic simulations and reducing model complexity of district heating and cooling systems by aggregation

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District heating and cooling (DHC) systems are considered cornerstones of a future decarbonized heat and cold supply due to their ability to integrate renewables and waste heat, provide flexibility by storage and advanced control methods as well as to represent the central hub of an interlinked overall energy system. These aspects lead to an overall more complex system as the number of technical components and potential interactions increase and the demands on the system grow. To cope with these challenges and to compare different system solutions, dynamic modelling tools are required. Nevertheless, it is computationally challenging to dynamically simulate large-scale DHC networks. One proposed method for improvement in this context is aggregation, which simplifies the topological complexities of the original network by reducing the number of branches and pipes. This study focuses on the analysis of the two aggregation methods, the Danish and the German Methods, on an existing district heating network with 146 consumers. The aggregated network with a lower number of consumers is compared to the original network in terms of accuracy and information loss. The results show that the CPU time in the simulation of this network can be speed up approximately 10 times by aggregating the network to 4 consumers. We will highlight current possibilities and limitations of both investigated methods and discuss further steps to enable dynamic simulation of large-scale DHC systems.

Keywords: District heating and cooling, network topology aggregation, dynamic modelling

Dr. Mag. MA MA **Gerald Schweiger** is a research associate and lector at TU Graz. He is working on modelling, simulation and dynamic optimization of energy related applications such as district energy systems. Currently he is working on his PhD in Environmental Systems Sciences.

4th Generation District Heating - a SWOT-AHP Analysis

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Previous research has shown that sustainable heating and cooling has a significant CO2 reduction potential. The fourth generation district heating (4GDH) is an integrated part of an overall smart energy system. In this paper, we present most important technology-inherent strengths and weaknesses, as well as opportunities and threats resulting from the technology environment (SWOT) of the 4GDH. In a two-stage process, we combined the SWOT-analysis with an analytic hierarchy process (AHP) in order to gain also information on the relative importance of SWOT factors based on expert judgements. In the first round, SWOT factors will be determined by ten to twelve qualitative expert interviews; in the second round, 30-40 experts will be asked via an online questionnaire to pairwise compare the identified factors according to their perceived relative importance. We defined the following groups of experts in order to cover different perspectives: (i) academia, (ii) policy maker, (iii) energy provider (network operators) and (iv) building project organizer. The statistical analysis and interpretation of the results, which are planned to be completed by June 2019, will allow a better understanding of most important SWOT factors of 4GDH and thus provide a solid basis for further developing highly integrated and decarbonized district heating systems in future.

Keywords: 4GDH, SWOT - AHP Analysis, Expert Assessment

Leire Chavarri is an engineer who has been working for the Energy Technology department of AAU. Her background on Renewable Energies and Indoor Environment has given her the skills to develop this DH project, showing to be a potential framework for further investigations in the field.

Flexible district heating network model that predicts mass flow, pressure and temperature losses

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Buildings play an important role in urban energy systems. It is no longer enough to simulate building energy use isolated from the supply energy source. Therefore, simulation and optimisation of a district heating networks needs of efficient, fast and realistic models of the individual network elements in order to correctly predict heat losses, temperature propagation, pressure drops and mass flow rates. In addition, the urbanization of new areas beyond the existing ones implies the expansion of the district heating network, demanding the new models to be flexible to adapt to the topology changes. This project presents the mathematical derivation and software implementation in Matlab of a thermo-hydraulic model based in the 'Element Method' in which the topology is implemented as an input, and temperature, pressure and mass flow are calculated according to the consumption from the nodes. It is a general tool that could be used as a framework due to its flexibility and adaptability. Currently the presented variables above are calculated for a linear network topology. However, future developments will allow to implement a matrix for more advanced topologies like a tree network. In addition, validation of the temperature loss along the pipes with experimental measurements during steady state conditions have shown a deviation of less than 5%.

Keywords: District heating modelling, mathematical modelling, Pressure losses, thermal propagation, thermal losses, Matlab, District heating network

Richard Büchele holds a degree in electrical and power engineering with focus on energy economics and supply. His work focuses on integrated strategic heating and cooling planning and analysis on different regional levels and favourable policy frameworks for renewable heating and cooling options

Opportunities and challenges of future district heating portfolios

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In this paper the opportunities and risks of different concrete portfolio options of an Austrian district heating (DH) supplier are assessed against the background of current challenges of the DH sector. Following steps are performed: (1) Analysis of status quo of the DH system (2) Analysis of current and possible future economic framework conditions (3) Definition of four concrete future portfolio options together with the DH utility (4) Modelling of the status quo and the future portfolios together with the respective framework conditions in a linear dispatch optimization model (5) Perform techno-economic analysis for each portfolio and for the different possible future framework conditions by calculating generated heat and full load hours and compare indicators like total CO2 emissions, total share of renewable heat and resulting levelized cost of heat. The assessment showed that the expected increased renewable power generation capacity is likely to increase volatility in future electricity prices with hours of both very low and very high electricity prices. This higher volatility of electricity prices results in higher technical flexibility requirements for the generation plants and there is a need for heat generation portfolios to respond to both high and low electricity prices. Under the assumptions the combination of heat pumps and CHP plants is well suited to use both, periods of low electricity prices and periods of high electricity prices.

Keywords: District heating; portfolio options; dispatch optimisation

Maria Jangsten

High Temperature District Cooling – Challenges and Possibilities

Maria Jangsten, Peter Filipsson, Jan-Olof Dalenbäck
Chalmers University of Technology

District cooling provides chilled water to its connected buildings with supply temperatures typically designed to be between 4 and 6 °C in order to meet traditional cooling supply temperatures of about 8 °C in the connected buildings. The technological development of cooling systems in buildings is advancing towards higher supply temperatures which allows for increased use of free cooling and enables two possibilities. Firstly, building owners may assess the feasibility of utilizing high temperature (free) cooling systems coupled with the ground, instead of connecting to the district cooling system. Secondly, it may be possible to utilize more free cooling from natural cold sources with higher temperatures in the district cooling system. The purpose of this study is therefore to explore the possibilities of increasing the temperatures in an existing district cooling system, focused on either increased return temperatures or both supply and return temperatures collectively. The study is based on operational data from an existing district cooling system and 32 of its connected buildings. The data has been visually analyzed by means of correlation plots to identify general trends along with operational issues. The results show that the temperatures in the district cooling system vary, but typically fail to reach design levels. This is a common problem called the low delta-T syndrome, which leads to wasted energy and increased costs. The results also show that increasing both supply and return temperatures in an existing district cooling system is possible based on the temperature requirements of the connected buildings' cooling systems. However, several challenges with higher temperatures were also identified, for example the lack of incentives for current customers to upgrade their building cooling systems. This study highlights the need to question the current temperatures in existing district cooling systems and it also emphasizes the need to re-think the traditional temperature levels when designing new district cooling systems.

Vittorio Verda is full professor at the Energy Department of Politecnico di Torino, Italy. His main research activities concerns the analysis and simulation of district heating systems and Thermal storage systems

Proper modelling approaches for operational simulation and optimization of large district heating networks

Elisa Guelpa, Vittorio Verda (presenter),
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Numerical models are of crucial importance for analysing the operating conditions of district heating systems and improving their performances both in normal operation and in the case of malfunctions. A particular aspect which might have significant effects on the energy exchanges and conversions, especially in large networks, is related with the thermal transients. This occurs for instance when the circulating mass flow rate changes due to night attenuations or when the supply temperature is dynamically adjusted in order to store heat in the network. Physical approaches can be adopted in order to take into account of the effects of network topology on the fluid flow and transient heat transfer. In the case of large networks or when super-real time simulations or optimizations are required, proper techniques to reduce the required computational resources must be applied. In this regard, the adoption of an equivalent topology description can be investigated using proper model reduction techniques. The goal of this work consists in analyzing the performances of network topology simplifications in terms of accuracy and computational time reductions while reproducing the thermal transients in district heating networks. Comparison is based on the analysis of the Turin district heating network, which is one of the largest networks in Europe.

Keywords: District heating, network models, reduced models, energy system operation

Inger-Lise Svensson is group manager of the Energy System Analysis group at RISE and holds a PhD in Energy Systems from Linköping University. She has extensive experience of research projects focusing on smart energy systems, energy system modelling, flexibility in the power system and integration of energy systems.

Reducing local energy system CO_2 emissions by exploiting differences in district heating and electricity CO_2 intensity in a local energy market

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To increase the flexibility of the energy system and reduce CO_2 emissions, the FED project aims at creating a local energy market for heating, cooling, and electricity at the Chalmers campus in Gothenburg. Since the campus energy system has three main energy carriers and includes both local production units and possible import & export to the external grids, there could be a significant benefit in cooptimizing the systems with a central goal, minimizing costs and possibly including a local CO_2 tax on the market. The production and consumption units, as well as import & export units, are represented by software agents bidding into a single local marketplace where bids are settled and communicated to the agents hourly. It was found that redispatching production units in the local energy system could achieve significant reductions in CO_2 emissions, but at the expense of increased primary energy usage in a Swedish context. In order to achieve significant CO_2 reductions new business models may be necessary. By exploiting the differences in CO_2-intensity of the electricity and the district heating grids reductions of up to 22% of CO_2 emissions may be achieved without increasing the operation costs. Without new investments up to a 30 % reduction is possible but at significant increases in operational costs (42 %). The achieved reduction is currently being evaluated in the now up and running local market.

Keywords: local energy markets, district heating, electricity, CO_2 reduction, dispatching, smart energy system

Monica Arnaudo is a researcher in the energy field at the Energy Technology department of KTH (Stockholm, Sweden). The overall objective of her work is to design and control heat and electricity systems at the lowest cost and with minimum (or even neutral) impact on the environment.

Techno-economic Assessment Of Distributed Heat Pumps Integration Within a Swedish Neighborhood

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Within the Swedish context, the current trend of relatively low electricity prices promotes the electrification of the energy infrastructure. The residential heating sector takes part in this transition by proposing a switch from a centralized district heating system towards a distributed heat pumps-based setting. This study aims at assessing the extent to which distributed heat pumps can penetrate an existing heat energy network while respecting the technical limitations of the electricity grid and the thermal comfort levels in the buildings. Different scenarios, based on forecasted electricity market prices, were developed for a neighborhood located in Stockholm (Sweden). For each scenario, the technical and the comfort conditions were assessed. Additionally, the average cost of heat generation was estimated in terms of levelized cost of heat. The scenarios related to the current electricity prices, show that distributed heat pumps can replace the district heating system by covering up to 30% of the heating demand. Within the future scenarios, if the electricity prices will increase, the penetration of distributed heat pumps can be limited to 15%. In terms of levelized cost of heat, a residential heat pump technology becomes competitive only within a scenario of decreasing electricity prices. In this case, a district heating system is characterized by an average cost of heat generation 7% higher compared to a distributed heat pumps option.

Keywords: Distributed heat pumps, district heating, electrical distribution grid, integrated energy systems

Olatz Terreros holds a Master's degree in Industrial Engineering from the Technical University of Bilbao (Spain). She has been working for the Austrian Institute of Technology since 2014 in the field of modelling and optimization of hybrid energy networks.

Pooling concepts for domestic heat suppliers in Austria

Olatz Terreros (presenter) [1], Johanna Spreitzhofer[1], Tara Esterl[1], Stefan Hauer[1], Fabian Leimgruber[1], Bernd Windholz[1], Christoph Bacher[2], Paul Sumerauer[2], Armin Wieser[2]
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The involvement of prosumers in the energy markets is promoted at a European level [1], since their flexibility can support the integration of fluctuating renewable energy sources. Automatically-controllable prosumer components, such as heat pumps, electric boilers, battery storage and e-vehicles are technically suitable for this purpose. The aim of the Austrian project *Flex+* is to enable the optimal integration of these components in the short-term electricity markets by means of pooling concepts [2].
The project provides a holistic approach since it optimizes the flexibility of several components simultaneously in a cloud-based system, offering system services across several electricity markets. Scalable optimization algorithms are developed at the pool and the prosumer level, considering the needs and interests of all stakeholders involved in the value chain.
This paper presents the first results of the project, with a focus on the operational optimization of heat pumps and electric water boilers installed in several households in Austria. Apart from the technical system characteristics, the modelling and optimization approach considers different electricity markets, such as the day-ahead spot and balancing market, including both the manual and automatic frequency restoration reserve (mFRR and aFRR respectively). The optimization model targets at the maximization of the market revenues while fulfilling the technical, economic, environmental and customer-oriented requirements.

Keywords: flexibility, operational optimization, electricity markets, heat pumps, electric boilers

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[2] "Flex +", project website, 2019. [Online]. Available: https://www.flexplus.at/

Tijs Van Oevelen (MS, PhD) performs research on thermal energy systems, in particular district heating and cooling, at VITO/EnergyVille.

Testing and evaluation of the STORM controller in two demonstration sites

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District heating and cooling (DHC) systems are recognized more and more as part of the solution to increase the share of renewable and excess heat sources in the heating and cooling sector. However, most existing DHC systems still rely on classic control principles. In order to unlock the full potential of these systems, more advanced control is needed to increase the overall system efficiency, reduce costs and lower carbon dioxide emissions. In the Horizon 2020 STORM project, a demand-side management system for DHC networks has been developed in order to reach these objectives.
This demand-side management system has been tested in two demonstration sites during the course of the STORM project. One is a typical 3rd generation grid in Sweden, in the town Rottne. The other is an innovative low-exergy grid in the Netherlands, in the town Heerlen, supplying both heat and cold simultaneously. Three different controller features have been tested: peak shaving (to minimize emissions from peak fuel), market interaction (to optimize CHP/HP production with respect to fluctuating electricity prices) and cell balancing (to reduce primary energy usage by aligning heat and cold demands). We will present the testing of the STORM controller in these demonstration sites, as well as the results that have been achieved.

Keywords: District heating, Demand-side management, Peak shaving, Integrated energy systems, Digitalisation

Shadie Broumandi holds an executive masters degree in sustainable energy systems. Currently, she is a student at the Department of Planning and part of the TECH Talents Research at the Technical Faculty of IT and Design at Aalborg University.

Residential heat consumption analysis towards 4th generation district heating: An econometric approach for Viborg district heating in Denmark

Shadie Broumandi (presenter),MSc, Ing., Prof.Poul Østergaard, Prof. Karl Sperling.
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Current district heating systems are in the transition to 4th generation district heating by lowering the temperatures. This will play an important role in transition to the future sustainable energy systems with more integration of renewable energy sources. This paper examines the relationship between the consumption pattern and the supply and return temperatures based on the log-transformed Cobb-Douglas production function. The analysis develops an econometric model for daily consumptions of 100 houses in Viborg district heating in Denmark. The performed models are segmented based on the motivation tariff structure of the Viborg district heating for the year 2018. The results show that there exists a relation between the consumption pattern as the dependent variable and the supply and return temperature as independent variables. Heat consumptions have a stronger reaction to variation of supply temperature whereas it has almost a constant value for all the variations in return temperature for all the segmented motivational zones.

Keywords: Motivation Tariff, 4GDH, Econometric models, Supply Temperature, Return Temperature Residential Buildings Consumption Patterns

Anders Dyrelund is one of Ramboll's leading energy consultants. He has specialized is the solution of techno-economic and organisational problems of district heating and cooling in cities and the interaction with the power system to create virtual electricity storages.

Smart integration of district heating, district cooling, waste water and ground source cooling

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The Public Utility of Taarnby was in 1980 responsible for water and waste water supply in the municipality of Taarnby. Responding on the Heat Supply act from 1979, the municipality joined the heat transmission company CTR and became a part of the Greater Copenhagen District Heating System. The result of the heat planning in Taarnby was that the utility established a district heating business unit, which invested in a new hot water district heating system. In 2019, total production capacity of this more than 30 year old system is 60 MW, and the heat loss is around 5%. Based on a screening of the district cooling potential, the utility identified a business case of district cooling to a new urban development and combining cooling and district heating with a heat pump installation (4,3 MW cold / 6,5 MW heat) and a 2.000 m3 chilled water tank. Moreover, the Utility could find two important synergies between the district cooling plant and the waste water treatment plant. The new district cooling plant and the chilled water tank could be located at the site of the waste water treatment plant. And the surplus capacity of the heat pump could be used for generating more heat based on heat from the treated waste water. Finally, there is a potential for increasing the cooling capacity to meet the demand of the second stage of the urban development by combining the heat pump with a 2 MW ground source cooling. The plant is under construction in 2019.

Keywords: District heating, district cooling, waste water, heat pump, chilled water storage, ground source cooling, electricity demand response

Gunnar Rohde is lead scientist and responsible for research and development of the Nerve Switch technology. He has a background in mathematical physics and more than ten years experience in energy conversion, storage and transmission. His main research interest are cyber-physical energy systems.

Improving Effectiveness and Efficiency of Smart Energy System using the Nerve Switch® Technology Stack

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A novel technology stack for improved management of electrical energy conversion and storage systems is introduced. The so-called Nerve Switch® is a family of integrated switch devices for an optimised and predictive control of, inter alia, electrochemical and photovoltaic energy systems on the level of individual single cells. In smart energy systems, the issue of electrical energy storage needs to be investigated more integrative together with electrical energy conversion and exchange technologies; this is due to the fact that transmission lines of different forms of energy are cross-linked bidirectionally in order to allow for an exploitation of synergies between them with regard to the overall energy system effectiveness and efficiency. Using the Nerve Switch® technology in smart energy systems enables matrix photovoltaic system, variable topology batteries and networked fuel cells, amongst others. This supersedes conventional energy management units as well as large parts of the necessary power electronics. In addition to reduced acquisitions and maintenance costs, this results in an increased operating range and a higher energy conversion efficiency. A sample concept of a smart energy system incorporating the Nerve Switch® technology stack is presented. Improved energy system effectiveness and efficiency are demonstrated using both an own model library and EnergyPLAN. The mathematical models are confirmed by experiments during several research and development projects.

Keywords: Nerve Switch Technology, Electrical Energy Storage, Peak Load Shaving, Reactive Grid Balancing, Matrix Photovoltaic Systems, Variable Topology Batteries, Networked Fuel Cells, Optimum Power Point

Hans-Christian Gils studied physics at the Universities of Konstanz, Padua and Hamburg. He joined the Energy Systems Analysis department of DLR in 2010. His main fields of scientific interest are energy system modelling, with special focus on flexibility options and the linkage of energy sectors.

Integrated modelling of the future electricity and gas supply in Germany

Hans Christian Gils (presenter), Hedda Gardian,
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The project "MuSeKo" aims to investigate the use of different technology options for the flexible use of electricity in all sectors of the energy system with an integrated model-based analysis. A special focus lies on the connection of business and macro-economic perspective by iterative simulations. One objective is the evaluation of economic efficiency, investment incentives and regulatory framework conditions. As part of the project, the REMix energy system model was expanded to include the gas sector. In addition to the production and conversion of synthetic fuels, this also includes the storage and transport of gases and their use in the electricity and heat sectors. The extended model allows the integral consideration of the electricity and gas system as well as the associated elements of the heat supply and transport sector. For different scenarios, the paper shows the impact of the energy system transformation on the use of the gas infrastructure, the possible contribution of an adapted operation of the electrical equipment in the gas network to the integration of fluctuating renewable power generation, and the potentials of the production and use of synthetic fuels (hydrogen, natural gas). Furthermore, the demand for different types of storage (power, heat, gas) as well as converters (e.g. heat pumps, cogeneration, hydrogen electrolysers and methanation facilities) in an integrated energy future energy system with high renewable energy supply share is evaluated.

Keywords: energy system modelling, sector coupling, sector Integration, electrification, REMix, renewable energy

Sina Steinle

Time dependent flexibility potential of Heat Pump Systems for Smart Energy System Operation

Sina Steinle (presenter), Martin Zimmerlin, Felicitas Mueller, Lukas Held, Michael R. Suriyah, Thomas Leibfried,
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The integration of multiple energy sectors such as electricity, heating and mobility into an overall Smart Energy System is a key aspect on the way to a fossil-free energy system. Exploiting the operational flexibility of these sectors will lead to an efficient operation of the Smart Energy System as a whole.

The use of heat pumps for the heating supply based on renewable energy resources is reasonable in many cases. Combining these heat pumps with a thermal storage, these systems can offer flexibility to an energy system based on fluctuating electricity generation. Flexibility can be defined as the capability to adapt an initial schedule in order to support the energy system in terms of provision of positive or negative power reserve.

In this paper an approach to determine the time dependent flexibility potential of a heat pump system is presented. The optimization-based approach considers all the constraints that result from the system topology including the required heating demand of the connected building. As a result of a case study, time series data for available flexibility in terms of power and energy is available. The initial schedule is the users cost optimal schedule in most cases. Therefore, the provision of flexibility can lead to higher cost for the system owner e.g. due to a reduced self-consumption of solar energy or a non-optimal exploitation of variable tariffs. The additional costs of flexibility provision are analyzed following the technical analysis.

Keywords: flexibility time series, heat pump operation, sector integration, smart energy systems

Søren Møller Thomsen is MSc. in Sustainable Energy with a special focus on electrical energy systems, system analysis, feasibility studies and energy markets. Søren has participated in a number of projects within sustainable development, smart energy systems and district heating and cooling.

Smart integration of fluctuating renewable energy into the energy system

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Ramboll has in a number of studies analysed the option to integrate renewable energy from wind, solar and waste heat into the energy system.
That includes a study for the Danish District Heating Association, Smart integration of renewable energy in the district heating system, a study financed by EUDP on Harmonized integration of electricity, gas and heat in association with Aalborg University and an ongoing EUDP financed study on Sustainable Energy Market Integration, in association with Syddansk University, Aalborg University and DGC.
The studies show how the energy system already today has the fully develop technology to transfer the heating and cooling sectors to renewable energy based on biomass, wind and solar a minor part of natural gas. The only missing technology, P2G is still in the development stage.
The key components in the energy system for this integration is the water based system: namely hot water district heating at modest temperatures, district cooling, large heat pumps, electric boilers, gas CHP and thermal storages for heating and cooling. The presentation will include an overall analysis, a proposal for market incentives and case studies

Keywords: Smart energy, renewable energy, district heating, district cooling, demand response, heat pumps, CHP, electric boilers

Giorgio Cucca is a PhD fellow at the NTU. His actual research field is energy efficiency applied to the building sector; in particular, he is working on deep refurbishment of domestic buildings with the aim of optimizing the management of complex energy generation and storage systems.

Co-simulation tool for hybrid energy system optimization

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The energy efficiency in building sector is attracting an always increasing interest in the scientific community. This sector has a strong impact in terms of greenhouse gases emissions; about 27% of the overall carbon emission in the UK comes indeed from the domestic sector. Considering the Climate Change Act the UK has committed to reduce by 80% its carbon footprint by 2050 compared to 1990 levels. In this context, the REMOURBAN H2020 project has carried out a deep refurbishing work on a small cluster of 10 homes implementing energy saving measure and a hybrid energy-supply system to satisfy the heating and domestic hot water demand of the homes. The system is designed as a low temperature district heating system (LTDH), and includes two ground sourced heat pumps (GSHP), photovoltaic (PV) panels, electric and thermal energy storage. Two different simulation models, validated by the data collected in-situ, showed that an 80% reduction in primary energy consumption is achievable. However, the management of the hybrid system leaves space to further optimization in order to find the most suitable control strategy from both the energy and economic point of view. With this purpose a co-simulation tool has been developed, coupling a model of the energy system built on Dymola-Modelica and the EnergyPlus model of the buildings; this allows to carry out a multi-criteria optimization. Expected results are minimization of energy consumption and operating costs.

Keywords: LTDH, Optimization, Modelica, Co-Simulation, Energy efficiency

Tekn. Dr. **Dietrich Schmidt**, head of department Heat and Power Systems of the Fraunhofer IEE in Kassel Germany, works with energy supply and use infrastructures with a key interest in low temperature district heating. He coordinates the subtask "demonstrators" in the IEA DHC Annex TS2 activity.

Implementation of low temperature district heating systems - Successful case studies of IEA DHC ANNEX TS2

Dietrich Schmidt (presenter)[1], *Kristina Lygnerud*[2], *Anna Kallert*[1]
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Low temperature district heating is recognized as a key technology for the (cost-) efficient integration of renewable energy and waste heat sources in our energy systems. Energy system studies indicate that a further development of low temperature district heating systems is needed for a decarbonisation of the heating sector. A deployment of local district heating schemes is mandatory to reach the set climate goals. To face these challenges research on innovative district heating concepts integrating decentral feed-in of renewable energy is required. Within the DHC Annex TS2 already realised low temperature community energy system concepts as well as planned or designed systems are identified and visualised in the project. Furthermore, projects showing an innovative use or operation of buildings are included. The different projects are assessed and compared. The presentation of the demonstrators is set up in such a way that knowledge is generated about the indoor heating system, the district heating system and of the competitiveness of 4GDH. The demonstrators included in the DHC Annex TS2 are analysed in regards to which elements of new knowledge they can generate. For each demonstrator there is a specific innovation in focus. The business model applied in each project documented as well. The paper presents and discusses the first results from ongoing current of research work within of the IEA DHC Annex TS2 on Implementation of Low Temperature District Heating Systems.

Keywords: low temperature district heating; case studies; innovative heat supply

Hjörleifur G. Bergsteinsson is a Phd fellow at DTU Compute in the Dynamical System section. His research will focus on energy informatics and forecasting using grey-box modeling and his main focus has been on developing new data-intelligence for the district heating sector using smart meters data.

Methods for Identifying Critical Temperature for Control of Low-Temperature DH Systems

Hjörleifur G. Bergsteinsson (presenter)[1], *Henrik Madsen*[1], *Jan Kloppenborg Møller*[1], *Henrik Aa. Nielsen*[2], *Markus Falkvall*[3], *David Edsbäcker*[3],
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Smart meters at the end-user in the energy sector creates the opportunity to develop data-intelligent methods for the district heating systems by using a large amount of fine-granular heat consumption time series from the end-users. We propose a method to estimate the temperature at an artificial critical point for the network by using quantile estimation using smart meter data. Hereby, we eliminated the need for physical critical points in the net. Also, we suggest a method to cluster households based on their consumption using time-of-the-week quantile distribution to identify critical points for control or problems. These methods were developed in the SCA project using data from Kraftringen and have shown promising results.We expect that creating artificial critical points will increase the savings by lowering the supply temperature and increase the efficiency of the temperature optimization by creating more accurate heat-load forecast using new data-intelligent methods from the smart meters. State-of-the-art methods in the district heating systems rely on predefined critical points in the network i.e. knowing the location of the lowest temperature in the grid and reference temperature curve which express the supply temperature as a function of the outdoor temperature. Hopefully, further analysis of meter data will create the possibility of having multiple temperature zones inside the network with different temperature levels by using temperature mixing and pressure pumps.

Keywords: Data-Intelligence, Low-Temperature, Meter Data, Clustering, Artificial Critical Point, Multiple Temperature Zones, Smart Cities Accelerator

Johannes Oltmanns is researcher and PhD fellow at the Institute for Technical Thermodynamics / Technische Universität Darmstadt. Main research interests: District Heating and Cooling, Combined Heat and Power, Network Temperature Reduction, Data Center Waste Heat Usage, Energy System Optimization

Decreasing the temperature of an existing district heating network

<u>Johannes Oltmanns</u> (presenter), F. Dammel, P. Stephan
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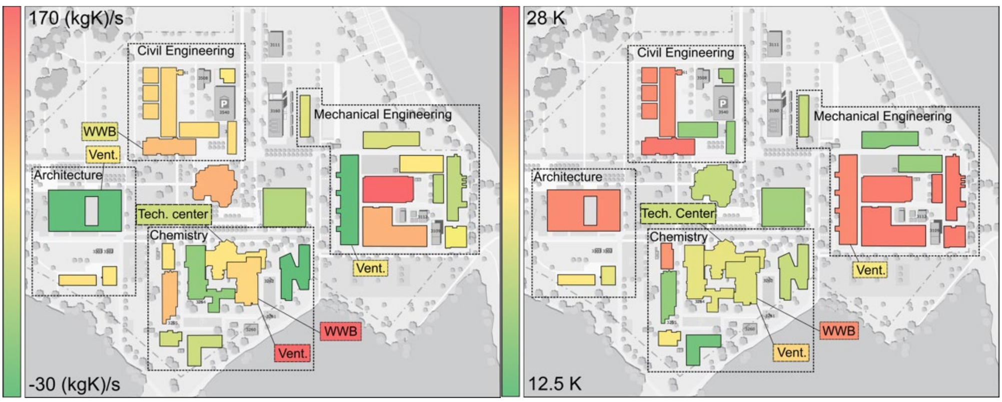
Low-temperature district heating reduces network losses and makes it easier to integrate renewable heat sources. Even more than supplying new districts with low temperatures, reducing temperatures in an existing district implies a great challenge. This study presents a strategy to reduce the temperatures in the network of TU Darmstadt's Campus Lichtwiese, erected since the 1960s. As not all buildings can be renovated at the same time, a list of possible measures is set up and key performance indicators (KPIs) are developed to determine where to apply which measure: Hydraulic balancing / renovation of the ventilation system: High building return temperatures indicate an unbalanced hydraulic system or unwanted supply to return shortcuts (e.g. in the ventilation system). The KPI for this measure is the temperature difference between the average building return temperature and the average campus return temperature weighted with the average building mass flow. Low-temperature surface heating: surface heating makes sense in buildings that show a high mean logarithmic temperature difference between the radiators and the room. Comprehensive energetic renovation: The most effective and most expensive measure is a renovation of the building envelope, especially in buildings with high area-related heat demands.



Comparison of building performance in terms of weighted average return temperature $\Delta T\ M_R$(left) and logarithmic temperature difference ΔT_m (right)

The goal for Campus Lichtwiese is to reduce the average district heating supply temperature from 89 °C to 55 °C and the return temperature from 60 °C to 40 °C until 2030.

Keywords: 4th generation district heating, return temperature reduction, surface heating

Johan Dalgren has an Industrial PhD

Temperature utilization in Thermal Energy Storage and its system impact on future (4th) Generation of District Heating Systems

Johan Dalgren (presenter)[1], *Fabian Levihn*[2], *Per Lundqvist*[1]
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Two of the main features in 4GDH are (i) lowered system temperatures, to allow more surplus heat from low temperature heat sources (LTS); and (ii) thermal energy storage (TES), to cover a varying heat load with that production. When the heat demand in the system is higher than this production, a discharge of the TES is needed. High electricity prices can also create a need for discharge, in order to replace heat production from e.g. heat pumps. In both cases the temperature in the TES should be as high as possible to enable existing LTS heat production, without peaking the supply temperature with additional expensive High Temperature Sources (HTS). Since, with a higher heat demand in the system both consumers and the network need higher supply temperature, which also would increase the electricity consumption for heat pumps. To be able to store heat from a LTS seasonally, this paper shows the importance of temperature utilization in both the TES and the system. To achieve a small temperature drop in the TES during storage, good insulation to the environment is necessary, but also to prevent the heat transfer within the storage between hot and colder parts. High thermal inertia in the storage is shown to have a negative effect on the return temperature back to the source when the TES is charged, and the supply temperature when discharged. A suggested system design allows for a HTS to enable seasonal storage of LTS, and creating more efficient low temperature areas in the DHS.

Keywords: Thermal energy storage; 4GDH; temperature utilization; energy efficiency; surplus heat

Tobias Ramm obtained his MSc degree in Energy System from the TU Hamburg.
In 2017, he started working as research associate at Institute of new Energy Systems, Technische Hochschule Ingolstadt. His research focusses on the investigation of district heating systems and the modelling with Modelica.

Development and investigation of optimised operation strategies for district heating systems with variable temperatures

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The growing share of fluctuating renewable electricity producers within the German energy system causes increasing demand for flexible consumers, producers and storage technologies to balance supply and demand. District heating systems (DHSs) with combined heat and power (CHP) units, Power-to-Heat (PtH) applications and thermal energy storage (TES) capacities can be one of these flexibility options. In this context, the investigation of a novel DHS equipped with central heat pump (HP) and decentral HPs delivering variable supply temperatures ranging between 25°C and 80°C, as shown in Figure 1, is performed.

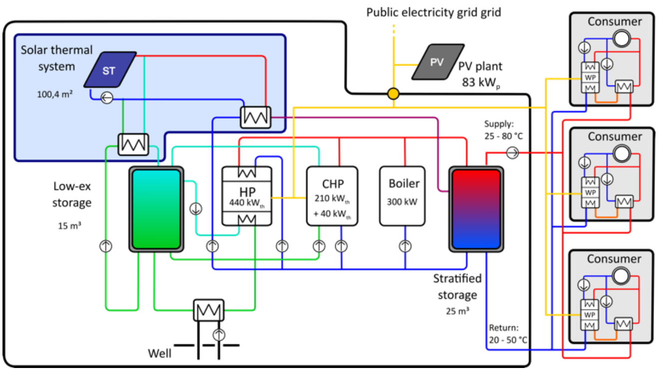

Figure 1. Scheme of novel DHS with variable grid supply temperatures

Since this new approach was installed for the first time, there is a high potential for improvement. The optimisation procedure is described subsequently:
1) Identification of optimisation potentials
2) Analysis of optimisation potentials
3) Development of ideas for advantageous solutions
4) Simulation of developed solutions
5) Implementation of advantageous solutions
6) Evaluation/proof of concept

The identification of optimisation potentials (1) led to detailed insights regarding the DHS´s performance and revealed challenges associated with the novel system approach as well as further optimisation potential. The present study focusses on technical improvements aiming for an economical optimum. Future work addresses the ecological optimisation and intelligent sector coupling approaches by utilising TES opportunities to shift electrical demand and production.

Keywords: District heating, variable supply temperatures, heat pump, operation strategies, measurement data, Modelica

Vilhjálmur Nielsen and **Christian Anker Hviid** combine expertise in Energy Planning, Energy Savings and indoor Climate in their common research that is focusing on how building control systems and control strategies can be improved in order to achieve energy savings and better indoor climate.

Preparing a school building from 1920's for low temperature district heating while improving indoor climate by use of wireless sensors

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Old poorly insulated buildings with legacy building control systems represents a challenge for district heating systems that aims to reduce temperatures in order to reduce costs and increase the ability of using renewable energy. This paper describes a study made in the winter of 2018-2019 in a school building from 1920's that both suffered from low thermal comfort and high return temperatures to the district heating system. Wireless thermal sensors were placed along the heating and hot water pipes in the building and indoor climate sensors were placed in the rooms. By systematically eliminating failures in the heating system and correct settings of radiator thermostats it was possible to lower the return temperature from 46 degrees to 31 degrees by increasing the supply temperature and thus increase radiator capacities resulting in better thermal comfort. The study identifies the few rooms where the heating capacities of the radiators are low compared to the current use of the rooms and thus also reduces potential renovation needs to these rooms. The paper describes the steps taken and results of the study that recommends a control strategy for buildings and reduces the potential costs of improving thermal comfort in old buildings.

Keywords: Low temperature, thermal comfort, control strategy, wireless sensors, renovation, old buildings, radiator capacity, return temperature, renovation, thermostat settings

Morten Karstoft Rasmussen has a background in nanoscience and physics from Aarhus University, and have previously worked in the field of metrology at the Danish Technological Institute. Now he is employed as a Data Scientist in the Analytics Team at Kamstrup, focusing on digitalization within district energy.

Data-driven decision support for optimisation of heat installations

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Integrating more green and sustainable energy sources into the district heating system requires utilities to lower temperatures in the network. The challenge regarding forward temperature is to run the production as close to the limit as possible while still meeting their customers' comfort level. Lowering return temperatures on the other hand is less straightforward because they are so closely linked to what goes on inside the buildings. Smart meter data and analytics can help utilities identify conditions that could be optimised such as the end users' heat installations. Often, these will have been installed incorrectly or be faulty in some way, or conditions may simply have changed leaving them no longer optimised for a particular house or purpose. The challenge this poses for most utilities is that their responsibility ends on the primary side and neither home owners nor professionals, e.g. plumbers, have the overall performance of the district heating system as their primary focus. Also, it can be complex finding the cause and most suitable solution standing on site. At the International Conference on Smart Energy Systems and 4th Generation District Heating, we wish to unfold the importance of data-driven decision support for home owners and professionals for the purpose of trouble shooting and optimisation of heat installations. We will also share our experiences on how digitalisation enables district heating utilities to work on this important area.

Keywords: Analytics, smart meter data, low temperature district heating

Etienne Cuisinier is doing his first year of PhD and has a dual master's degree in ORCO (Operation Researchs, Combinatorics and Optimization) from Grenoble INP* - ENSIMAG, and in industrial engineering from Grenoble INP* - Génie Industriel.
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Energy system investment planning: a methodological review towards a new approach at the territorial level

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The energy transition brings decision makers, utilities and scientists to rethink current energy systems. Designing energy systems is a complex task that requires support from modelling tools. Multiple questions arise when looking at investment planning for energy systems: optimal system architecture, technology options or capacities are frequent research topics. For these purposes, modelling tools based on different optimization methods have been developed, such as metaheuristics or mathematical programming. Selecting a suitable tool is a key step: some guidelines can be found in the literature. Yet, few specifically address their optimization capabilities regarding to their modelling assumptions, including assumptions about operational control. Based on a literature review, a new framework (Fig. 1) is proposed to identify and compare the potential decision support provided by different optimization tools, with respect to their core assumptions (Fig. 2). Tool limits, hypothesis and the decision support they can provide are identified. The implications of some simplifications are mentioned as well as current strategies for overcoming them. Thereupon, a new method is intended to account for a more realistic operational and control model. This work is the first part of a broader research project. It aims to optimize the investment planning for a territorial multi-energy system. It focuses on the optimization method: what are the current limits and how can they be addressed?

Keywords: Multi-energy systems, micro-grid, territories, investment, planning, bottom up, optimization, modelling method, operation, control, data aggregation

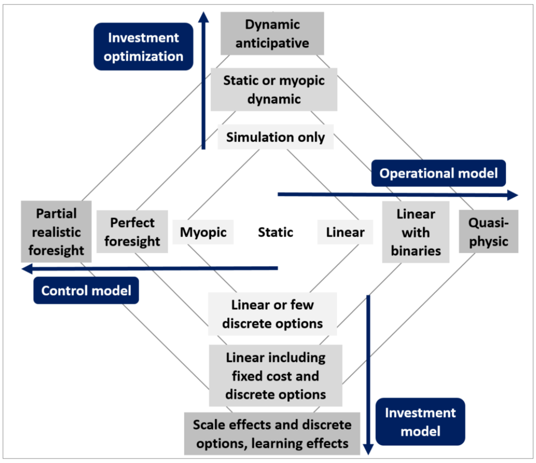

Fig. 1: Simplified version of the proposed classification framework for energy modelling tools according to their optimization capabilities and underlying assumptions.

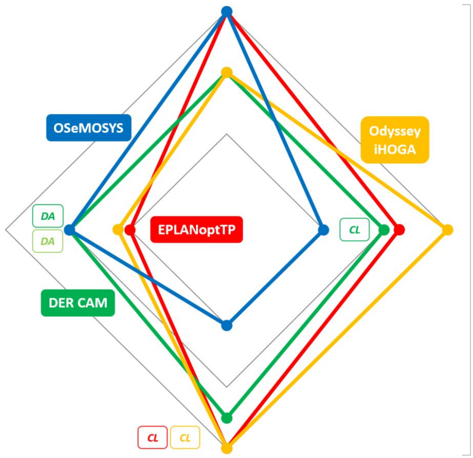

Fig. 2: Examples of tools positioned within the framework (Fig. 1). Identification of the use of data aggregation (DA) methods and computation limit (CL) points related to the optimization method.

Thibaut Résimont is achieving a PhD about the design of district heating networks by developing optimization models used as decision tools. This work is realized in the frame of a project about the development of a district heating network recovering energy from waste incineration.

A multi-period MILP model for the topological optimization of a district heating network

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District heating networks require large investment costs such that they have to be built in an optimal way. The development of optimization models able to assess the best solutions to implement for given available heating sources and heating consumption profiles in a specific geographical area is useful to provide a topological optimization and optimal sizing of these systems. A Mixed Integer Linear Programming (MILP) model for the optimal outline of a district heating network is developed in this paper. This model can be used as a decision tool able to provide the optimal heating sources to install at specific locations and the pipes to build in order to minimize the total costs of the system. The model is applied to a case study of a district with some available heating sources and various heating demand profiles.

Keywords: District Heating, Energy Integration, Heat Storage, Multi-period, Optimization

Can Tümer is a consultant in the Heat Transfer and Fluid Dynamics department of TNO. In a broad sense, his research covers various applications of fluid dynamics and fluid structure interaction problems in the energy industry. One of his focal points is topology optimization for energy grids.

Challenges in Heat Network Topology Optimization

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Different stakeholders have different design considerations that shape a heating grid. In short term, these range from achieving lowest ownership costs to preventing monopolies. In long term, project developers focus on how uncertainties of design parameters (e.g. demand/supply, heat prices) affect the grid design and, ultimately, the business case. Currently, heat grids are designed through the evaluation of manually drafted topologies. Since there are many design options and uncertainties in the parameters, it is infeasible to evaluate all possibilities, leading to suboptimal designs. In this paper, numerical optimization approaches will be discussed that can assist with the conceptual grid design in a systematic manner to achieve an improved network topology. The required mathematical formalization and solution methods pose several challenges which will be demonstrated using an inhouse developed Energy Systems Simulator, e.g. • computationally efficient treatment of large number of discrete options for connecting network actors (consumers, producers, prosumers) and pipelines taking into account construction scheduling. The optimization problem leads naturally to a computationally costly mixed integer problem. • increasing network fairness (for all network actors), which can be cast into a binary quadratic program. • incorporation of parameter uncertainty to achieve a robust topology design. • defining appropriate KPI’s to be optimized.

Keywords: Heat network, Heat grid, topology optimization, network fairness, uncertainty, mixed integer programming, KPI

Ana Turk obtained her MSc degree at Department of Energy Technology from Aalborg Univesity focusing on frequency regulation. She is now a PhD in the Centre for Electric Power and Energy at Technical University of Denmark focusing on future integrated energy systems.

Two – stage stochastic day-ahead scheduling for integrated heat, electricity and gas system as MILP model

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The future power system with a high renewable energy sources capacity introduces challenges in the power system stability and security. A prominent solution for a more efficient energy system is the integration of different energy sectors. This work formulates the mathematical model of an integrated energy system (IES), incorporating electric power, natural gas, and district heating systems, as a two-stage stochastic problem focused on minimizing the total expected IES cost. In the first stage, operating points of generating units are scheduled, while in the second stage wind production is realized and accommodation of wind production uncertainty through reserves is performed. This work contributes in several aspects. The multi-period two-stage stochastic IES model is formulated with a number of realistic scenarios and assigned probabilities to account for wind power uncertainties. Optimized scenario generation algorithms provide a more advanced way to describe stochasticity for the uncertainty resulting in reduced computational burden. Furthermore, the IES mathematical model is linearized to ensure a global optimum. The detailed mixed integer linear optimization problem is formulated in GAMS. The results show the enhancement of IES efficiency, flexibility, sustainability, and security through multi-energy system integration and coordination. Including stochasticity in the problem formulation reduces the total expected IES cost and optimizes the reserves.

Keywords: Integrated multi-energy system, electric power, district heating, natural gas, mixed integer linear problem, stochastic day-ahead scheduling, renewable energy sources, wind production, uncertainty

Danica Maljković has a background in power engineering and 15 years of experience in the energy sector. Her special interest is in district heating (technical/planning and regulatory area), renewable energy with a focus on geothermal and marine energy and energy efficiency in industry.

Machine learning algorithms for modelling consumption in district heating systems

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The building sector in the EU spends about 40% of the total final energy, from which a further 80% is energy for space heating and domestic hot water preparation. In recent years, there is an extensive development of the Data science and Big Data sciences and the wider application of machine learning methods to the analysis of the various areas. In this research machine learning algorithms and statistical methods were implemented together with comparative analysis and identification of the most appropriate algorithm to model and plan consumption in district heating systems. Several machine learning algorithms where implemented, namely multiple linear regression, logistic regression, decision trees, random forest and support vector machines. Each of these algorithms was implemented over a dataset of approximately 1,750 district heating substations in 600 buildings in two towns in Croatia. The focus of the analysis is the comparison of the consumption in the years prior and after to instalment of heat cost allocators. as well as the overall modelling of the consumption in district heating sectors taking into consideration both technical and behavioral influential parameters. Results of modelling and predicting consumption in district heating systems using above mentioned five machine learning algorithms are presented and interpreted while each of the algorithm is evaluated accordingly.

Keywords: district heating, heat cost allocator, energy efficiency, machine learning, logistic regression, decision trees, random forest, support vector machines

Henrik Dalsgaard is Vice President in COWIs District Heating business unit and project manager and expert in industrial energy efficiency, use of industrial waste heat for district heating and use of biomass and biogas for energy production.

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A pathway to emission free district heating in a world driven by data and electricity – Case: data center waste heat utilization.

Most of the energy used in industry ends up as heat in one way or the other. Some of this heat can be captured and used for other purposes instead of being wasted after it has served its primary purpose.
The Danish energy policy has for decades had this focus on waste heat utilization both internally in industries, but also for external use through nearby district heating networks.
Examples of waste heat utilization are shell refinery in Fredericia, Aalborg Portland cement plant in Aalborg, Dupont's plant I Grindsted, but also a lot of smaller industrial companies across the country are integrated in the local heat infrastructure and in that way an important factor for the local community's sustainable development.
The Danish waste heat utilization contributes to 3 % of the total district heating consumption in Denmark.
Waste heat utilization from data centers is an untapped potential for low cost heat generation globally and with an increasing demand for data storage, and consequently a boom in construction of new data centers, it is now that the synergy between society and data industry has to be reaped before the data-center train has left the platform.
The huge amount of electricity used for processing and data storage is all transformed to warm air that is cooled by ordinary ventilation of the data centers. The amount of electricity used in data center industry is estimated to grow to as much as 7 TWh/y or 17% of the Danish electricity consumption in 2030. The Electricity could with the right technology the right positioning and the right framework be a significant player in the Danish heating sector.
Instead of letting the energy disappear in open air it is possible to collect and utilize most of the energy through heat pumping. COWI is and have been heading several of the current studies for waste heat utilization and is involved in a number of large date center projects.

Keywords: Energy efficiency, Surplus heat utilization, Data Centers, Industry, District Heating

Stefan Holler is professor at HAWK. His research fields cover DHC, CHP and RE systems with a focus on technologies for transformation of energy systems. He avails of significant experience in the management of diverse national and international projects. Stefan Holler is vice chairman of ETP DHC+.

Methodology to assess the potential of waste heat from industry, service sector and sewage water

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Point sources of high-grade waste heat from heavy industry have been covered in previous studies. The MEMPHIS project goes one step further by integrating waste heat sources within a particular city district to the district heating system (DHS) whilst using an internationally applicable approach to improve transparency in the field of research. A methodology is provided to evaluate and map the potential of waste heat from industry, service sector and sewage water by using internationally available open data. A generic methodology has been developed and validated, firstly, to assess waste heat potential from industry and service sector on a district level and secondly, to model the sewage water flows in a city and to assess the heat recovery potential from the sewer system. Country-specific key figures to assess waste heat potential in cities are presented. An online platform provides this information for companies, cities and local energy suppliers. The methodology has been applied to three representative cities in DE, AT and UK and is implemented into the online platform “MEMPHIS WASTE HEAT EXPLORER”. A market and impact analysis for DE, AT and UK shows the different regulative boundary conditions and barriers that currently limits the wider integration of these waste heat sources into district heating systems. Aligning the methodology with internationally available open data enables the application of the results from the MEMPHIS project for other countries as well.

Keywords: District heating systems, waste heat, service sector, sewage water, business model, market analysis, modelling, open data

Johannes Pelda is PhD fellow in the field of energy systems. His focus is especially on district heating systems. He researches on methodologies and strategic approaches to integrate renewable energies reasonable considering also the utilisation of low-grade waste heat sources.

sim4dhs – an algorithm to simulate tree and meshed district heating networks dynamically

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The demand for reduction of CO2-emissions in heat generation and the slowly decreasing heat demand due to sequentially improved thermal insulation of buildings require district heating systems (DHS) of the 4th generation, which allow the integration of CO2 neutral renewable heat or waste heat sources, lower heat losses in the distribution network and reduce piping costs. The transition of existing DHS towards 4th generation over a long-time / strategic period involves several economic and technical challenges such as temporarily thermo-hydraulic bottlenecks. How can strategies look like to break thermal-hydraulic restrictions reasonable by including decentralised thermal storages, heat pumps utilising low-grade waste heat or sufficient demand side management? To gain an optimized and trend setting approach it is essential to simulate the system dynamically. This work presents results of a quasi-dynamic model to simulate tree-like and meshed DHS, which are validated through comparison with state-of-the-art software. Finally, the algorithm is the foundation for a newly developed and open-source dynamic simulation of the thermal-hydraulic behaviour. The results contribute to develop strategies when embedding spatial distributed technologies to cope with thermal-hydraulic bottlenecks. The used language python ensures open source and broader application of the methodology.

Keywords: tree, meshed district heating networks; thermo-hydraulic restrictions; validation; integration of thermal storages; utilisation of waste heat; dynamic simulation; demand side management

Charlotte Marguerite is working at Cenaero as a senior research engineer. She is involved in Belgian regional projects related to smart buildings and buildings efficiency. She worked previously on district heating networks integrated in smart cities.

Optimization of flexible electricity loads of a buildings cluster using distributed model predictive control

K. Siau [1]; C. Beauthier[1], C. Marguerite (presenter)[1], J. Blanchard[2], C. Verhelst [3], R. De Coninck[4]
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Various solutions for smart grids are being developed and tested in many countries to reach high energy efficiency and costs reduction at district scale. At building scale, control systems have been developed as Demand Response measures, with the objective to shift thermal or electrical loads while maintaining indoor comfort. However, solutions for smart control of individual buildings at district scale are still missing. In this work we developed an efficient control interface for tertiary buildings integrated to an intelligent electrical network. It combines Model based Predictive Control (MPC) at building scale for energy demand optimization and distributed algorithms at global scale to aggregate multiple problems sharing common objectives and/or constraints linked to the network. Two iterative algorithms were implemented: 1/ a dual decomposition method (global problem included into the local ones and managed by an aggregator) 2/ a cooperative MPC method (data sharing among the MPC problems). These algorithms were tested and compared to the centralized approach on different numerical cases (such as avoiding network congestion, following a global load profile or optimizing local renewable energy use). The results show that these methods can reproduce the results of the centralized problem while being scalable and efficient for large number of buildings. An added value of the developed interface is its range of application which is not restricted on the model complexity.

Keywords: Model Predictive Control; energy demand optimization; distributed algorithms; smart grids

Johannes Röder is a PhD candidate and research associate. He is focusing on renewable, integrated and resilient district heating systems. Johannes Röder holds a MSc in mechanical engineering and has experience in geothermal district heating systems, energy efficient buildings and system analyses.

Design of renewable and system-beneficial district heating systems using dynamic emission factors for grid-sourced electricity in optimization models

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Sector-coupled energy systems, especially power-to-heat technologies, have a great potential for building up renewable district heating systems. Furthermore, district heating systems can support integrating volatile wind and photovoltaic energy sources and resolving congestions within the electricity grid, which cause cutoffs in renewable electricity generation. This paper presents a design approach for flexible power-to-heat based district heating systems. A linear investment and unit commitment optimization model for district heating system has been built up. By considering local time dependent emission factors for the grid-sourced electricity, which contain information about local wind turbines cutoffs as well as the emission intensity of the overall electricity generation, a renewable and system-beneficial design is accomplished. With this method the minimal plant size of heat generation units and thermal storages can be determined in order to achieve a certain level of emission reduction with respect to minimum costs. Using constant emission factors for grid-sourced electricity is not an option anymore. Within the project QUARREE100 an existing district in the provincial town Heide in Northern Germany has been examined. In that case an emission reduction of 80 % compared to a fossil heating system can be achieved by power-to-heat capacities equal to the maximum winter heat load of 2 MW combined with a thermal storage of 50 MWh net capacity.

Keywords: district heating, sector coupling, optimization models, dynamic emission factors

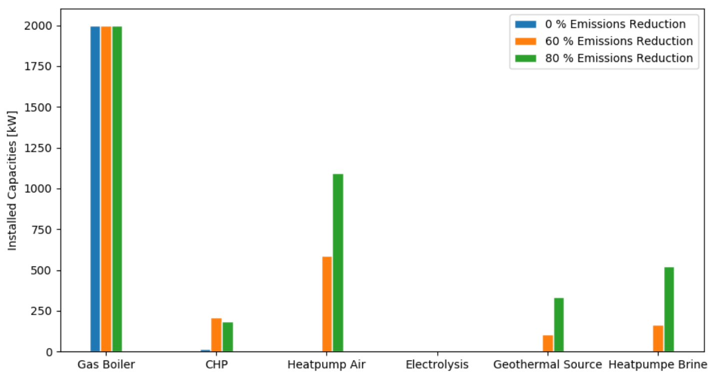

Figure 1: Cost-optimal capacities of heat generation units for different emission limits for a district heating system in Heide (SH, Germany). Gas boiler capacities constant due to back-up reasons. Optimization period one year with a time resolution of one hour an

Saleh Mohammadi is currently employed as a Postdoctoral Research Fellow at TU Delft Faculty of Architecture, where he is working on designing integrated energy systems for the built environment with a high renewable share. He received his PhD from TU Eindhoven in 2016 in ”Smart Energy Systems”.

Optimization of temperature levels in decentralized solar feed-in heat grids, A case study of Dutch refurbished building in a residential neighborhood

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[1] Delft University of Technology
[2] Deltares
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For a considerable number of existing residential neighborhoods, there is a limited amount of sustainable heat sources locally available. In addition, to make these neighborhoods energy neutral, ambitious insulation measures are often not feasible. Previous studies have shown that for these neighborhoods the best solution consists of decentralized solar feed-in low-temperature (LT) heat grid integrated with ATES. One of the promising systems is integrating individual roof-mounted PVT with heat pumps (HPs). By connecting PVT to heat pumps and a collective LT-ATES grid, highly efficient heat grids are feasible. By this, not only a higher temperature can be achieved in the grid which makes the HP efficient, but also the PVT ensures the regeneration of the ATES over the year. In an ongoing project, DeZONNET, the feasibility and optimization of this system is investigated. The goal is to develop an integrated system that connects PVT on building level to a LT-ATES grid in existing neighborhoods. The thermal output of the PVT depends greatly on the temperature achieved: the lower the temperature, the higher the annual output. The main quest of the paper is to examine the effect of decentralized PVT temperature output on the whole system efficiency as well as the number of PVT panels needed, as the later both relates to spatial needs and costs. The analysis will led to an optimized temperature output of the PVT, considering both efficiency, costs and spatial needs of the panels.

Keywords: Low Temperature Heat Grid, Decentralized Solar Feed-in Heat Grid, Photovoltaic Thermal Collector (PVT), Heat Pumps (HPs), Aquifer Thermal Energy Storage (ATES), Temperature Levels

Tom Brown studied physics in Cambridge, before completing a PhD in London. After a postdoc, he switched fields into the grid integration of renewable energy. In September 2017 he was awarded his own at KIT to further his research on the interactions between transmission grids and sector coupling.

The cost-benefit of transmission grid reinforcement in a highly-renewable European smart energy scenario

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Coupling electricity to other energy demand sectors, such as heating, transport and industry, and to other energy carriers, such as gas and heat, is a necessary part of reducing the use of fossil fuels in a smart energy system. This is driven partly by the large expandable potentials for wind and solar electricity generation, partly by the high efficiency with which electricity can be used in, for example, electric vehicles and heat pumps, and finally by the flexibility enabled by sector-coupling. However, if sector-coupling drives up electricity demand by a factor of up to two, at the same time as electricity supply is dominated by variable renewables far from load centres, this has the potential to overload today's grid. To assess this challenge, we consider the optimal investments and operation of an hourly, several-hundred-node, sector-coupled model of the European energy system as carbon dioxide emissions in electricity, transport, building heating and industry are forced down to zero. The high spatial resolution of the model allows us to assess in detail the impacts of grid bottlenecks. We find that deep decarbonisation is possible without grid reinforcement, but it requires smart system operation and additional costs evaluated in this model to be around 100 billion euros per year compared to cost-optimal grid expansion. A low level of grid expansion, comparable to that planned by system operators today, can still deliver half of these cost savings.

Keywords: Smart energy systems, renewable energy, grid integration

Dominik Dominković is currently a postdoc at DTU Compute. He finished his PhD at DTU Energy in 2018. He has published many journal papers, focusing on integrated energy systems modelling, energy system optimization, urban energy models and analysis of decarbonization in the transport sector.

Demand response in district heating systems: on operational and capital savings potential

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Most district heating systems are operated in an inflexible way, mainly due to legacy operational software, business-as-usual state of mind and lack of awareness of new possibilities brought by digitalization. Moreover, shares of variable renewable energy generation are continually increasing, which causes large oscillations in electricity prices in day-ahead markets. Electric boilers are already common in district heating systems, and it is expected that heat pumps will gain a stronger ground in the future, resulting in variation and uncertainty in the cost of heat production. This calls for a more dynamic representation of the district heating system, including the implementation of demand response that could react to the cost of heat production. In order to check the potential of increasing the flexibility in district heating systems based on a price signal, a high-level energy planning model was soft-linked with the flexibility algorithm, including feedback between them. The case study was carried out for a district heating grid in Zagreb, Croatia. Flexibility was utilized by varying the forward temperature in district heating systems by 3.5 °C compared to the baseline operation. Compared to the relevant literature, flexibility was used much more in our case often due to the accurate representation of the flexibility dynamics. Results showed that both capital and operational savings were achieved. The best performing scenario resulted in socio-economic savings of 5.4%.

Keywords: Energy flexibility; energy planning; variable renewable energy; integrated energy systems; capacity extension planning

Hironao Matsubara’s research fields are statistics database, scenario study, policy framework and business model of renewable energy in Japan. Degree as doctor of Engineering for Energy Conversion from Tokyo Institute of Technology in 1990.

Current Status and Issues of Renewable Heating System towards 4DH in Japan

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The DH system infrastructure is important in the development of renewable energy heat utilization. However, in Japan, the market size of the district heating is only 0.01% in terms of area of supply. In terms of the number of customers, compared with the 29 million users of the city gas that covers up to the home, there are 36,000 users of DH, and the district heating business is limited to a few large-scale customers. In Japan ,most resources of district heating (DH) system are limited to fossil fuels such as city gas, limited to urban areas where heat demand is concentrated, and demand for cooling demand is higher than heating, so the first generation DH, steam supply is still mainstream, but third-generation hot water supply using CHP exhaust heat has begun. In the municipal waste incineration facilities by local governments, the heat supply by hot water is partially provided, but the developments of DH infrastructure have not progressed at all. Therefore, there is almost no DH system that uses renewable energy such as biomass as a heat source, but as a fuel for relatively small-scale DH system, woody biomass attracts attention from the aspect of resource circulation, and the introduction of DH systems has begun in several local cities. We analyze and evaluate the current situation and issues of these DH systems and consider for the development of 4DH system in Japan.

Keywords: Renewable Energy, Biomass, District Heating, 4DH

Dr **Behzad Rismanchi** is a Mechanical Engineer, Certified Energy Manager (CEM) and Certified Energy Auditor (CEA) with more than 10 years' experience in Design, Optimization and Research in Thermal energy storage, Energy Management Systems (EnMS) and Computational Fluid Dynamics (CFD).

Resilience metrics and drivers for energy system planning at the community level

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To address the ever-increasing concerns of resource depletion and climate change and their irreversible environmental impacts, new research, technologies, and investments have targeted energy efficiency and renewable energy systems. A key question is to what extent can we reconfigure our energy system without compromising the system's resilience against chronic stresses and extreme events. The concepts of system reliability, robustness and resilience are discussed with respect to commonly expected events (such as component failures, overgrown vegetation, and animals) and extreme events (such as hurricanes, flood, gas explosions, and manmade disasters). Unlike reliability, resilience is not a common consideration in energy planning at the community level and there is no universally agreed-upon method or metrics for measuring or estimating resilience and defining the mitigation strategies. This paper investigates some of the existing definitions of energy resilience as well as categorised metrics and drivers for community energy planning for both existing projects and new developments. The energy resilience framework will support engineering design and energy planning at a community level.

Keywords: Energy resilience; renewable energy sources; reliability; sustainability

Tetsunari IIDA is a founder and chairperson of ISEP, as leading authority on Renewable Energy also a Social Innovator

Issues of renewable energy heat policy and establishment of 4DH forum in Japan

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In Japan, compared to fossil fuel boilers installed in facilities with high heat demand and residential heating and hot water supply, very few installations using renewable energy such as wood biomass and solar thermal facilities have been introduced. The price of fossil fuel is generally higher than that of renewable energy such as biomass fuel due to the environmental tax introduced in some European countries such as Scandinavian countries although Japan has an environmental tax, its tax rate is very low, and it is natural in the heat sector that transition to renewable energy has hardly progressed. Nevertheless, the target of the heating sector of renewable energy is not clearly defined, and the policy remains as a subsidy to the installation equipment. As a forum of research, research, opinion exchange, exchange for realization of heat policy of renewable energy and development of heat utilization, our institute is working on 4th Generation District Heating in Denmark ahead in Europe. We have established the "4DH Forum Japan" in October 2018, with interested researchers, businesses, national & local governments people and NGOs. With networking both domestic and international organizations relating 4DH that underpinned the EU Heat Roadmap towards the realization of the Paris Agreement. In addition to sharing knowledge and experiences by holding research meetings and workshops, we aim to share networks and knowledge for promoting the use of renewable energy heat in Japan.

Keywords: renewable, 4DH, heat, Japan, "Japan 4DH forum", multi platform, Policy, District Heating,

Marie Münster is Professor in Energy System Modeling at DTU. She specializes in the field of national energy modeling with focus on technologies producing heat, power and transport fuels and on analyses of the role of district heating and the gas system in future energy systems.

What is the benefit from sector coupling?

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With the increasing supply from variable renewable energy sources, there is a growing need for flexibility in the energy systems. One potential way of achieving this is through sector coupling, such as coupling the power sector with the heat sector through heat pumps and electric boilers. Different assessments have been made; regarding to which extent this flexibility measure will have a benefit to the overall energy system. On the one side, power-to-heat may assist in providing flexibility to the power sector by utilizing e.g. wind power when excessive and storing the heat, and on the other side it may assist in reducing greenhouse gas emissions in the district heating sector. In this paper a review of recent studies is undertaken, which illustrates:
1) the current state-of-art in terms of power-to-heat for district heating and the prospects for development
2) the potential benefits from a system perspective
3) barriers for implementation Conclusions show that there is a potential benefit if implemented smartly, and that the benefit depends on availability of other flexibility measures such as other energy storages, flexible production and power transmission.

Keywords: Sector coupling, smart integrated energy systems, Power-to-Heat, flexibility, district heating, district energy, variable renewable energy

Daniel Møller Sneum is a former analyst in IEA, Green Energy and PlanEnergi. He conducts his PhD-studies at DTU Management. Focus in the research is on integration and flexibility in the interface to the electricity grid. His research includes analyses of regulation of district energy in Nordics, Baltics and US.

Evaluating barriers to flexible grid integration of district energy

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To facilitate an efficient energy system, sector coupling should integrate energy sectors flexibly. Many barriers exist for flexible integration, but their scale of impact is not always clear. We evaluate the consequence of adjusting and removing barriers to flexible integration in the interface between district heating and the electricity grid. To identify potential external effects, beyond those on sector coupling, we apply a broad set of analytic criteria. The criteria include those typically applied in energy system analyses (e.g. system costs), but also those relevant to policy (e.g. tax revenue). Thereby, we aim to provide results relevant for academia as well as policy makers. We focus on barriers identified for Denmark as part of the European energy system. Barriers categories include regulation, operational practices, and investor preferences. The analyses are performed in the energy system model Balmorel, to indicate the broader system impacts of barriers in Denmark. By analysing several combinations of barriers and their solutions, the results are scored according to the performance on the criteria. Results are expected to show the impact of barriers to flexible grid integration of district energy induced by must-run operation, electricity taxes, grid tariffs, biomass taxation, discount rates (a proxy for type of ownership) and bans on heat pumps. Results are under development and will be presented during the conference. This study is part of the Flex4RES project.

Keywords: barriers, district heating, variable renewable energy, flexibility, integration, sector coupling, energy system analysis, Denmark, Northern Europe, smart energy systems, district energy

Sylvain Quoilin obtained his PhD at the University of Liège in 2011. He is now assistant professor at the KU Leuven Belgium in the field of "Heat integration into smart energy systems".

Modeling the flexibility offered by coupling the heating sector and the power sector: an assessment at the EU level

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This paper explores the opportunities offered by the coupling between the power sector and the heating sector at the EU level. In particular, the aim is to quantify the amount of flexibility offered by heat pumps and CHP within district heating systems. To that aim, the EU version of DISPA-SET (an open-source unit commitment and optimal dispatch model covering the whole EU28 plus Switzerland and Norway) is used and adapted to take into account thermal storage coupled to district heating. If not smart management of district heating and thermal storage are applied, the effects of introducing combined generation and heat pumps are sometimes adverse. Higher peak loads and reduced flexibility caused by contractual obligations to deliver heat may not always facilitate the penetration of renewable energy in the energy system. However, by unlocking the flexibility linked to thermal storage, significant reductions in peak electricity demand are achieved and renewable energy curtailment is reduced. This reduction is highly dependent on the penetration of thermal storage and variable renewable energy in the system. To ensure the transparency and the reproducibility of the work, the model, together with the input data, are released as open-source and open-data. Both can therefore readily be adapted and re-used to simulate alternative scenarios.

Keywords: Flexibility; Sector coupling; Optimal Dispatch; District Heating; Modelling

Frederik Banis is a PhD student at the Technical University of Denmark. He focuses on Microgrid operation optimization using direct and indirect Model Predictive Control approaches. Implementation of these control strategies are achieved using an hierarchical control architecture.

Handling Uncertainty in Sector Coupled Systems using Dynamic Programming and Model Predictive Control

Frederik Banis (presenter), Henrik Madsen, Niels Kjolstad Poulsen,
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One central element for the operation of integrated energy systems is the determination of energy--associated prices. In some situations this determination is not possible --- for example when privacy restrictions apply. System Identification (SysID) techniques alongside Optimal Control and Dynamic Programming approaches can still allow for informed decision making. A core aspect in this setting is the determination of when to carry out SysID events. SysID can be expensive in monetary means but is in this setting required for the derivation of system knowledge. There is a trade--off in between an expensive SysID event at a given point in time and the expected benefit of additional system knowledge at a later point in time. Consequently, in some situations expensive SysID events are comparably more attractive. Dynamic Programming techniques allow for the examination of this trade--off such that the decision --- whether a costly SysID event can be beneficial in the long--run --- can be carried out based on informative grounds. In this paper we focus on informed System Identification using Dynamic Programming techniques considering approaches outlined in [1] such that we can optimize the overall economic performance of a system including price--responsive units. [1] Tor Aksel N. Heirung et al. “Model Predictive Control with Active Learning under Model Uncertainty: Why, When, and How”. en. In: AIChE Journal 64.8 (2018), pp. 3071–3081.

Keywords: Dynamic Programming, Demand Response, System Identification, Model Predictive Control, District Heating System , Sector Coupling

Naoya Nagano is PhD candidate at the Graduate School of Engineering, Tohoku University. His main area of research is design and analysis of energy system.

Introducing sector coupling to utilize renewable resources for regional decarbonization in Japan

Naoya Nagano (presenter)[1], *Toshihiko Nakata*[2],
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In Japan, the share of renewable resources in total primary energy supply is 6% in 2017. This is because transmission grid has constraints for renewable resources' access owing to their intermittency. In order to offset the intermittency and promote the use of renewable resources, it is necessary to introduce sector coupling into Japanese energy system. Sector coupling is an innovative concept to implement smart energy system by integrating energy career such as electricity, heat and transportation fuel. This research aims to design and evaluate energy systems considering sector coupling in northeastern area of Japan. In the analysis, we got hourly surplus power based on the examination of both supply from renewables and demand for electricity. We also calculated hourly heat demand for commercial and residential sector. For meeting heat demand with surplus power as well as excess heat from waste incinerator, there are some options such as power-to-gas (P2G) or power-to-heat (P2H), individual or centralized. Thus, we conducted a case study of evaluating designed energy systems. As a result, the surplus power is estimated as 430 PJ/year in case of introducing all the renewable potential in northeastern area of Japan. This shares 52% of current demand for heat and transportation fuel in the area. The introduction of sector coupling made energy system efficient and decarbonized. Moreover, the superiority of P2H became clear in terms of higher energy efficiency and lower costs.

Keywords: energy system, sector coupling, power-to-gas, power-to-heat, cost analysis

Steven de Jongh is a research assistant at the Karlsruhe Institute of Technology. Since February 2019 he has been researching machine learning in the field of distribution grids. His interests lie in the integration of renewable generation plants, sector coupling and the integration of EVs.

Machine learning based state-estimation in sector coupled energy distribution systems

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Secure grid operation must be ensured in future distribution grids in which coupling of electricity, gas and heat sectors will play an important role. The grid operator should prevent over- and under-voltages as well as line overloading. To make right decisions regarding the grid operation, it is necessary to have the most accurate possible knowledge of the current state of the grid. Since the number of sensors in electricity and gas grids is limited, the actual state of the energy system cannot always be calculated analytically. State estimation techniques allow estimating the actual state of the grid while taking measurement errors into account. Classical methods, most often based on Weighted-Least-Squares (WLS), have some drawbacks. WLS depends on the knowledge of the line and pipe parameters of the system which are not always known in reality. Mathematically under-determined WLS systems can only be estimated with pseudo measurements. Coupling elements between the sectors are hard to implement with WLS. In this work, a data-driven approach is taken. The proposed machine learning method does not suffer from the problems of classical WLS. The estimator is validated using a coupled electricity and gas benchmark grid. The effects of volatile feed-in and storages were taken into account. It is shown that the proposed method can cope well with noisy and missing sensor data. The inference method doesn't depend on a model of the physical system and can learn from sensor data only.

Keywords: state estimation, coupled energy system, distribution grid, machine learning, electricity grid, gas grid, sector coupling

Morten Jordt Duedahl is the Business Development Manager at DBDH (Danish Board of District Heating). His job is "Promoting District Energy for a Sustainable City Transformation". In this capacity he works with governments, cities and other stakeholders to strengthen the development of district energy.

Internal Rate of Return and how it affects development of city wide district heating projects

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Internal-rate-of-return (IRR) is the theme discussed all over when planning how to establish a DH systems. IRR is still to be understood in detail and is at the same time a very important part of understating how to roll out city-wide networks. Organisations hoping to enjoy the benefits of DH must understand what the IRR means and how a low or a high level of IRR affects the roll-out. Not least how high IRR will limit city-wide expansions of district heating. Cities discuss how to buy back their DH companies from private companies, how they can get private funding involved and how to become more competitive and efficient all over the world. This discussion often leads back to one of private ownership or council led ownership and then again to the accepted level of IRR. The objective of this is to demonstrate the effect of roll-out of DH based on 2 different ownership models. Roll out controlled by a municipal led (non-commercial) DH company is compared to the roll-out possible when done by a classic commercial ESCO. It is shown that careful planning will enable a municipal led district heating company to roll out district heating network city wide often with a wider spread or lower cost than is done by a commercial company. It has been demonstrated that the roll our will differ substantially having effects on e.g. the carbon-agenda, fuel poverty and job creation. The paper also discusses how the difference in the expected IRR can be used for different purposes over time.

Keywords: Internal rate of return, city wide district heating, ESCO, limits to expansions, IRR,

Dejan Ivezić is Professor in Energy and Sustainable Development at University of Belgrade – Faculty of Mining and Geology, Head of the Center for Energy. He has more than 20 years of experience in research and involvement in Serbian energy planning and policy making.

The State and Perspective of Belgrade District Heating System Development

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District heating (DH) system in Belgrade provides energy for heating of more than 21 million m2 in households (app. 50% of all households), public, commercial and industry sectors. Public Utility Company "Beogradske elektrane" is responsible for all segments of the DH system operation. The system is fueled mostly by natural gas. The share of renewables is negligible. The research analyzes effects of implementation of two main projects proposed in the Development Strategy of the PUC - the introduction of heat energy produced in Thermal power plant "Nikola Tesla A" (600 MW) and in CHP waste incineration plant in Vinča (56.5 MW). These projects are analyzed from energy and environmental aspects. Projections of fuel mix in Belgrade DH system for the period until 2030 are presented supported with appropriate indicators (P/F ratio, import dependency, primary/final energy consumption, GHG and pollutants emissions). Projections are given and indicators are calculated for 4 different scenarios, analyzing different demand of consumers (BAU, energy efficiency measures, measurement of delivered heat, and payment based on the measured value, etc.) Although obtained results show different levels of reduction in energy consumption and emission, the production of heat energy remains based on combustion processes. Therefore, some other, non-combustible energy sources should be considered in order to make the Belgrade DH system more sustainable.

Keywords: district heating, Belgrade, development

Nyamtsetseg Ivanov

Applicability of Solar-Assisted Heat Pump System for Space Heating in Mongolia

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The energy supply of Mongolia is based on coal-fired thermal power plants, which at present accounts for 90% of total energy generated. The heat supply is an urgent need for not only urban but also remote areas brought on by the long and severely cold winters. Burning coal directly is one of the main reasons for air pollution in the biggest city in Mongolia, Ulaanbaatar. The World Health Organization (WHO) listed Ulaanbaatar as one of the three most polluted cities in the world. The Government of Mongolia is obliged to provide heating for its citizens. Consequently, the most suitable solution is to investigate environmentally friendly and energy efficient technologies using renewable energy for a future of sustainable development and green growth. The objectives of the paper are to investigate the applicability of a solar-assisted heat pump system (SAHP) to be installed for space heating of a 2-floor building to replace conventional coal-fired heating systems. TRNSYS software will be used for system design and simulation. A solar-collector heating system and SAHP and compared them with a conventional coal-fired heating system with respect to energy consumption and CO2 emissions. The basic initial conditions were set the same for each system. To optimize the base model of the SAHP system, TRNSYS simulations were performed with various different parameter settings so that all parameters and relationships could be examined.

Keywords: the solar assisted heat pump system, energy supply, TRNsys,

Romanas Savickas is part of the UNEP-DTU Partnership: Senior Advisor, Principal/Managing Consultant and Expert for Global Energy, Energy Efficiency, District Heating development, Buildings EE, Energy Mapping, Big Data, Digitalisation. Intercontinental experience in Latino America-Europe-Asia and other regions.

Challenges of Development of Green Field District Heating technologies in Latino America. Temuco city case in Chile

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Temuco city in Chile has the third worst air quality in Chile. 93 % of the particulate matter in the winter months is caused by burning firewood in older woodstoves in residential one family buildings. Inefficient combustion of firewood also produces contaminants such as formaldehyde causing many negative effects on the health and causing 400-500 premature deaths per year. The objectives of the UN District Energy in Cities Initiative are to accelerate the use of district energy in Chile as a means of reducing air pollution, greenhouse gas emissions and of improving social outcomes as energy poverty. The Temuco city is a pilot city in order to evaluate trends in energy consumption for heating, to identify potential locations for district energy and technical-economical viability. For district heating development should be identified the costs, benefits, and barriers including policy and regulatory issues, to identify business models that can be used for district energy, to provide recommendations on policy, regulatory and financial instruments to overcome barriers to district energy and to accelerate the use of district energy in Chile. The main key findings and challenges of development of green field district heating technologies in Latino America will be presented.

Keywords: District Heating, Green Field project, Energy Efficiency, Wood Stove, GHG emission reduction, Air pollution, Climate mitigation, State policy, Chile, Temuco

Susana Paardekooper is PhD Fellow at Aalborg University, working on the design of heating and cooling strategies in the context of sustainable energy systems from a technical, economic and planning perspective in the context of Heat Roadmap Europe and the UNEP District Energy in Cities Initiative.

Heat Roadmap Europe: Heating typology as a basis for policy recommendations

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The main barrier for heating strategies in Europe has historically been the dependence on local implementation, often without a national framework. This paper proposes a typology that identifies categories of different countries as a basis for appropriate discussion of low carbon heating implementation. This typology is based on 14 heating strategies developed in the Heat Roadmap Europe project, which consider current and future developments, demand- and supply side energy efficiency, hectare-level thermal mapping and energy system analysis. The 4 identified types are those with a heat planning tradition, aiming to move toward SES and 4GDH systems; those with deteriorating heating infrastructure, aiming to refurbish and upgrade both the building stock and the existing heating infrastructure; those which have a developed heating sector in the form of gas infrastructure, but which will require radical transition to decarbonise; and those where the heating demand (and subsequently need for transition) is underrated, even though the potential for energy efficiency is large. By identifying different types of countries and identifying their shared and differed attributes, it is possible to use a comparative approach as a basis for policy recommendations and focus the analysis of what is required in a heating transition. This in turn can contribute to a more detailed analysis of the specific and general aspects of the heating and cooling sector.

Keywords: Energy efficiency, district heating, heat strategy, heat policy, energy system analysis, typology

Zhuolun Chen

Fast Decision-Making Tools for District Cooling Project Development in Urban Planning Stage

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District cooling system is a kind of public service that supplies chilled water at a certain temperature to end-user buildings through distribution pipelines. Due to a larger network of energy sources, this kind of systems can include more renewable energy, thermal storage and so on, which are difficult or not economic viable for single building. As a result, higher district energy efficiency, more sustainable energy supply and higher energy reliability can be expected. This paper introduces the implementation work District Energy in Cities Initiative under UN Environment has done in developing countries. In order to facilitate the project development procedure in urban planning stage, a rapid assessment tool is developed to evaluate the potential of districts for technical and economical viable district cooling systems. The tool can link to the results of energy mapping, get data from urban planning or master planning and then directly assist the urban energy planning. It can give the results including district cooling system capacity, investment and OPEX, environmental benefit, requirements of lands and pipelines, and parametric analysis on three most sensitive factors for economic analysis etc.. The aim of the tool is to support fast decision making on urban planning stage and give out basic conditions of different urban planning plans so as to decide where and what kind of district cooling systems should be developed. It also gives out results that can be used as input for detailed analysis once decisions are made and feasibility study is required.

Keywords district cooling, fast decision-making tools, energy planning

Mei Gong is associate professor and has been employed at Halmstad University since 2011. She is very curious on all exergy analyses. Sven Werner is professor emeritus at Halmstad University since 2018 and he is still curious on district heating.

Enhanced Biomass CHP plants for district heating systems

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In Sweden, located in North Europa, more than half of the total heat demand in buildings is met by district heating, but only just above one-third of the heat supply comes from Combined Heat and Power. In this paper, a new enhancement of biomass CHP plant is explored. The modification is that a large absorption heat pump is used for the heat supply to the district heating network. This new solution has so far never been implemented outside China. The benefits will be more electricity from lower condenser pressure and more heat obtained from flue gas condensation. The drawback is that the absorption heat pump will require extracted steam that will decrease electricity generation. In order to estimate the offset between the two benefits and the drawback, a simplified model has been developed to study a typical Swedish biomass CHP plant located in Lund. This enhancement could be part of the transition from third generation district heating (3GDH) to fourth generation district heating system (4GDH) by introducing efficient heat supply plants in current systems with high distribution temperatures. Several cases studied concerning both 3GDH and 4GDH have been compared to reference cases. The results show that the enhancement is a possible way to prepare for future 4GDH. Further investigations are recommended concerning pre-investment in absorption heat pumps as a transition strategy for new CHP plants originally designed for return temperatures of 20-30 ºC.

Keywords: district heating, CHP, absorption heat pump, biomass

Hanne Kauko works as research scientists at SINTEF Energy Research. She works primarily with thermal system modelling and thermal energy storage. Her fields of interest include industrial clusters, as well as refrigeration and heat pumping systems.

Local thermal grids with waste heat utilization: low- or medium-temperature supply?

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The interest towards low-temperature district heating (DH) and the resulting possibilities to utilize low-temperature waste heat sources is increasing among DH suppliers. Due to temperature requirements for domestic hot water (DHW) production and existing older buildings however, heat at higher temperature levels is required at most customers. The supplier must thus choose between true low-temperature distribution, with distributed heat pumps to increase the temperature level locally at the buildings, or medium-temperature distribution at temperature levels able to cover the entire heat demand. This problem is relevant at Leangen in Trondheim, Norway, where a new residential area will be built. The plan is to utilize waste heat available at 40 °C from a nearby indoor ice rink in a local thermal grid. Two alternative supply temperature levels are being considered: 40 °C, with distributed DHW production using CO2 heat pumps, and 70 °C, applying a centralized NH3 heat pump to lift the waste heat temperature to the required level. The local grid will be connected to the primary DH grid for back-up and auxiliary heating when needed. In this study, the dynamic simulation program Dymola has been applied to evaluate the two heat supply alternatives. Results from yearly simulations were applied to compare the systems with respect to the total demand for both heat and electricity, peak demands and their occurrence, as well as the demand for additional heat supply.

Keywords: Low-temperature district heating, 4th generation district heating, waste heat utilization, CO2 hot water heat pumps, thermal system modelling

Hannes Poier works as a project manager in research and development at S.O.L.I.D. GmbH since 2013 where works in the field of solar district heating, absorption heat pumps, dynamic simulation and coordinates appropriate projects.

Model-based control of absorption heat pumping systems

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Motivation: Absorption chillers and absorption heat pumps are, due to their ability to combine a wide range of technologies, systems and applications, of particular importance for increasing the efficiency of energy systems and the share of renewable energy, respectively. Currently, a significant part of the possible applications cannot be realized (e.g. process heat/cooling, district heating feed in) since the controllers applied are not able to meet the requirements. Additionally, the lack of systematic approaches leads to higher effort during the design and commissioning of the systems. Goal: Increasing the efficiency, reliability and effectiveness of existing applications and enabling additional applications by developing a method for the model-based control of absorption heat pumping systems The method should be as systematic and modular as possible in order to provide a broad basis for further development of the control for both common working fluid pairs (ammonia/water, water/LiBr) as well as for cooling and heating applications. The control should be able to provide the heat very accurately at the required temperature levels even in the case of strongly varying operation conditions. An increased range of use and higher system reliability can be expected. Method: Based on a comprehensive experimental validation, including test runs derived from the practical requirements, the potential of improvement shall be evaluated for different categories of applications.

Keywords: Absorption heatpump, Absorption chiller, model-based control, heating and cooling, district heating, energy efficiency

Marco Cozzini, senior researcher at the Institute for Renewable Energy of EURAC Research (Bolzano, Italy), has over 10 years of experience in the field of renewable energy. He has worked in several European projects, concerning – among others – energy efficiency and district heating and cooling.

Techno-economic scenarios for neutral-temperature district heating and cooling networks based on decentralized heat pumps

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District heating and cooling (DHC) systems have proved to be more efficient than individual heating and cooling technologies in several contexts. Nevertheless, conventional thermal networks still suffer of some drawbacks. Focusing on heating, the relatively high distribution temperatures give rise to non-negligible thermal losses, in spite of high-quality insulated pipes. Moreover, the supplied heat often includes a high share of fossil fuel energy. It is hence important to look for new solutions with lower thermal losses and higher shares of renewable sources. This work presents an overview of the results found in the recently closed FLEXYNETS project, focusing on neutral-temperature DHC based on decentralized heat pumps (HPs). In the context of heating only, this concept is sometimes called “cold district heating”, where typical sources for these applications are ground source heat or water basins. In several cases, the urban environment offers low-temperature waste heat sources at more convenient temperatures (e.g., refrigeration applications), allowing for better coefficients of performance (COP) of the involved HPs (COP = 5 or more). Moreover, in several regions the inclusion of cooling (thanks to HP reversibility) can unlock new energy balance possibilities. This contribution highlights the barriers and the opportunities for this innovative solution, providing a techno-economic analysis for a few scenarios related to this approach.

Keywords: District heating and cooling, heat pumps

René Kofler is a Research Assistant at the Section of Thermal Energy, Department of Mechanical Engineering at the Technical University of Denmark. His current research focuses on the improvement of heat pump performance through gradual heating and/or cooling using tank systems.

Performance analysis of a heat pump system, providing district heating and cooling through gradual heating and cooling

René Kofler (presenter)[1], *Bhargav Reddy Kondakindhi*[1], *Brian Elmegaard*[1], *Claus Madsen*[2], *Lars Olsen*[2], *Wiebke Brix Markussen*[1],
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The combination of district heating and cooling by the use of a co-generation heat pump is a promising technology for a fully renewable energy society. It allows for providing heating and cooling from renewable energy carriers, like wind and solar. The use of only one technology to provide both heating and cooling, is advantageous for the investment costs of the system. However, the big temperature lift between the hot and the cold side leads to reduced COPs of the system and hence to higher running costs. In previous works, the use of a tank system for gradual heating on the hot side of the heat pump was examined. The tank system consists of one charging tank, allowing for multiple circulations through the condenser, and a bigger storage tank, where the hot water is stored. Both tanks were assumed to be ideally stratified. It was shown that improvements in COP of up to 35 % compared to a conventional heat pump could be achieved. Within this work, the inclusion of an additional tank system on the cold side, for gradual cooling was examined. The tank system is identical to the one on the hot side, including a charging tank connected to the evaporator and a bigger storage tank for the storage of cold water. The investigation was done by numerical modelling of the heat pump and the tank system. The results showed that the introduction of the additional tank system for gradual cooling leads to further improvement in COP.

Keywords: Heat pump, COP, District heating, District cooling, Tank system

Jakob Zinck Thellufsen is an Assistant Professor at Aalborg University. He has a PhD degree in energy planning on the focus of integrating smart cities with smart energy systems. He work with energy systems modelling on different geographical scales, going from cities to regions and countries.

Benefits to single country modelling: Comparing 14 interconnected individual country models to a single 14-country model

Jakob Zinck Thellufsen (presenter), Susana Paardekooper, Miguel Chang, Henrik Lund, Aalborg Unversity

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With the transition to 100% renewable energy system based on variable renewable energy, the flexibility of the energy system has to be found in the overall system design. To increase the potential system flexibility, one of the main sectors that needs to transition is the heating sector, which needs to both become more efficient and utilize more electricity instead of fuel. This can be done through the implementation of heat pumps either in individually heated buildings or in connection with district heating systems. The Heat Roadmap Europe 4 study investigates how this can be done in 14 European countries. These countries will furthermore all be interconnected through transmission cables, which also will generate flexibility. The combination of gaining flexibility through the heating sector and interconnection can be analyzed either using a single aggregate model of all the countries, or by modelling each country by itself and modelling the exchange of electricity between each country. This study investigates the consequences of those two different approaches in terms of assessing the integration of renewable energy in future renewable energy scenario. This is done by utilising EnergyPLAN and the new tool EPlanFlow that combines individual country modelling in EnergyPLAN with an analysis of transmission of electricity based on the PowerFLOW tool.

Keywords: EnergyPLAN, Smart Energy Systems, District heating, Energy system analysis

Ewoud Werkman has been working in R&D in the energy sector for the past 10 years with a focus on adding smartness to the energy system. He has a background in Computing Science. The past years, he works on heat networks and is creator of the HeatMatcher, an agent-based controller for heat networks.

Modelling Energy Systems in an interoperable, reusable and comparable way

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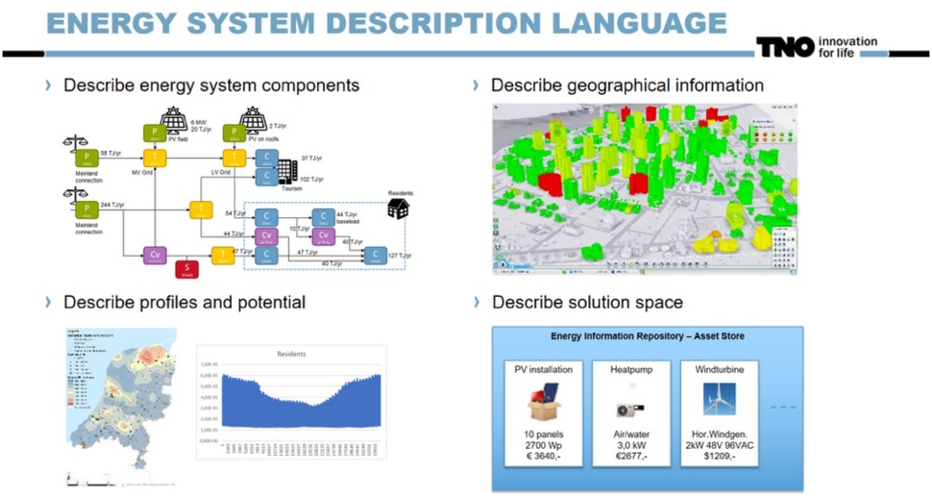
The energy transition from fossils to renewables requires a major change in the construction and operation of the energy system. The energy system is a complex system with numerous relations and dependencies. Therefore, the impact of possible changes is hard to determine. To constructively reason on these changes of the energy system, an objective and complete information basis is necessary. The Energy System Description Language (ESDL) provides this information basis. It is a modelling language created for describing the components in an energy system, their relations among each other, and their state throughout the transition. ESDL describes components at a certain level of abstraction by their basic functionality in five categories: Production, Consumption, Storage, Transport and Conversion. This approach not only leads to an integral understanding of energy system, but also to interoperability and information exchange between different calculation models used in consultancies to governments, allowing them to compare and reuse inputs and outputs of different calculation models of different consultants. ESDL enables energy modelers to describe a complex energy system in a generic way. It can also serve as a basis for a standard energy component repository. The language is open source and machine readable with several language bindings, so creators of energy transition calculation tools and GIS applications can support ESDL to enforce the interoperability of their products.

Keywords: Energy Transition, Tooling, Modelling, Interoperability, ESDL, calculation models



Kristine Askeland is a PhD fellow in the Energy Planning Research Group at Aalborg University. Her current research revolves around hydropower in smart energy systems, focusing on the modelling and analysis of hydropower's role in renewable energy systems in a European context.

The impact of geographical resolution of hydropower in energy systems modelling

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Hydroelectricity constituted 36.9% of the electricity produced from RES in Europe in 2016 and is the dominant RES source in several European countries. Unlike wind and solar power that are variable in their nature, hydropower can, if combined with a storage facility, be regulated both on hourly and yearly levels. However, where wind and solar to some extent are versatile in terms of placement, hydropower facilities are dependent on specific geographical conditions related to inflow and height differences. Furthermore, hydropower facilities and storage facilities are geographically co-located. Today, energy system simulation tools are used for production planning and strategies for the development of energy systems. These tools typically aggregate hydropower production and storage capacities, ignoring the geographical dependencies. In this paper the authors seek to assess the effects of aggregating hydropower in the practice of energy systems modelling. The paper focuses on the European energy system, and through analyses of information related to geographical distribution of hydropower production capacities as well as of model results using different geographical resolutions, the effect of aggregating hydropower in simulation models is analysed. The geographical resolution tested ranges from regional level to European level. Furthermore, it is analysed what effect the geographical resolution has on different types of facilities: run-of-river, reservoir and pumped hydropower.

Keywords: Hydropower, RES, Energy Systems Modelling, Energy System Analysis, Europe, geographical resolution

Roberto Vaccaro is researcher in Eurac since 2010, with experience in developing sustainable energy plans at municipal level and more recently in energy modelling at regional level. At present he is attending an executive PhD at "Politecnico di Milano" on energy and economic modelling.

A computational model linking EnergyPLAN with Input-Output analysis for evaluating the economy-wide impact of the transition at regional level

Roberto Vaccaro (presenter), Matteo Vincenzo Rocco,
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Future scenario analyses carried out at regional level with energy simulation models are widely used. However, they lack the ability to assess the economy-wide economic and environmental impact of the investment needed and of the new deriving energy consumption patterns. On the other side, for their complexity and data requirements, combined energy-economic analyses are often limited to national or international studies. The paper presents a soft-linked model combining EnergyPLAN and a Hybrid Units Input-Output (HUIO) regional model. EnergyPLAN is setup and run according to several prescriptive scenarios, identifying optimal Pareto solutions in terms of energy costs and CO2 emissions. Such results are pre-processes and incorporated into the HUIO model, thus evaluating the economy-wide economic and environmental impacts of several scenarios defined for the South-Tyrol Province (Italy). The impacts are assessed for the following categories in terms of change in: added value and taxes (i.e. Gross Domestic Product), imports, total industrial production and emissions. These variables are evaluated for different economic sectors. Cross-referenced with appropriate data, these results may support local decision makers in quantifying the economy-wide impact of future technology development scenarios, identifying potential areas of investment and policy intervention to effectively and proactively support the sustainable energy transition.

Keywords: Energy scenarios, EnergyPLAN, Input-Output Model, Economy-wide impact analysis, Decision support system, Policy makers, Regional energy transition, Renewables, Efficiency, Emissions

Salman Siddiqui is a PhD candidate at the UCL Energy Institute whose research involves energy systems modelling with a professional background in energy industries. His current research focuses on exploring the benefits of integrating district heating into the UK power system.

A novel method for forecasting electricity prices in a system with renewables and large-scale grid storage for use in energy system models

Salman Siddiqui (presenter), Salman Siddiqui, Mark Barrett, John Macadam
UCL,

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In future UK energy scenarios with a high level of electrification, it is expected that a large share of electricity will be generated from renewable sources. To accommodate the variability of renewable generation, flexibility in the network is vital. An important flexibility option is grid scale electricity storage.

A simulation is made of the electricity system with variable renewable generation, electricity storage and flexible high carbon generators, assumed to be gas CCGT, for various UK scenarios. The simulation uses historical hourly meteorology to drive models of demand and renewable variation, and the consequent input/output operation of storage and dispatchable generation to balance differences between demand and renewables. A marginal cost method is devised to calculate the storage, renewable and dispatching capacity and operational costs incurred in each hour. These cost structures can form a transparent economic base for informing market design and setting prices for use in energy system models.

Results show that while marginal costs for renewable generation are relatively low, reliance on battery storage for backup particularly during peak periods can result in high electricity prices and without a significant increase in projected fossil fuel or carbon prices, traditional high carbon electricity generators will still be cheaper to operate. This work will form the basis to analyze the impact of large-scale thermal energy storage on electricity prices.

Keywords: Renewable Power, Electricity Market, Battery Storage

Isabelle Best is PhD candidate at the Institute of Thermal Engineering at the University of Kassel, Germany. Her focus is on low-temperature district heating and solar heat integration. She is conducting system modelling and dynamic simulation for system design and optimization.

SYSTEMATIC INVESTIGATION OF THE BUILDING ENVELOPE'S AND HOT WATER PRODUCTION SYSTEMS' INFLUENCE ON THE HEAT LOAD PROFILE OF DISTRICTS

Isabelle Best M. Sc. (presenter)[1], Hagen Braas M. Sc., Dr. Janybek Orozaliev, and Prof. Klaus Vajen

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Utilities face the challenges of how to design district energy systems future-proof for new building developments and assessing the economic viability of supplying new building developments. At district level, the construction density, number of floors, and building composition shape the heat demand and heat load profile. Therefore, three residential districts of 130 buildings are defined representing medium sized developments in the rural, suburban, and urban context. A building typology of 10 fictitious buildings in the range of 100 m² to 1,200 m² space area were calculated. Depending on the district type, the building composition was varied forming the three exemplary residential districts. The building envelope characteristics were varied according to the German energy saving ordinance (see Figure 1). Further, the impact of hot water preparation system: buffer storage, instantaneous hot water preparation, and hot water circulation was systematically analysed via dynamic simulations. The connected load decreases by around 36 % through the increase of building envelope standard. The share of hot water net energy demand on the total heat demand increases from 17 % to 37 %. Heat load curves were classified, and key performance indicators developed. The combined effect of district composition, building envelope standard and hot water preparation system on the heat load was studied and will be discussed in detail during the presentation.

Keywords: district heating for rural, suburban, and urban districts; hot water preparation; generation of net energy demand curves; calculation of heat load curves; new residential buildings

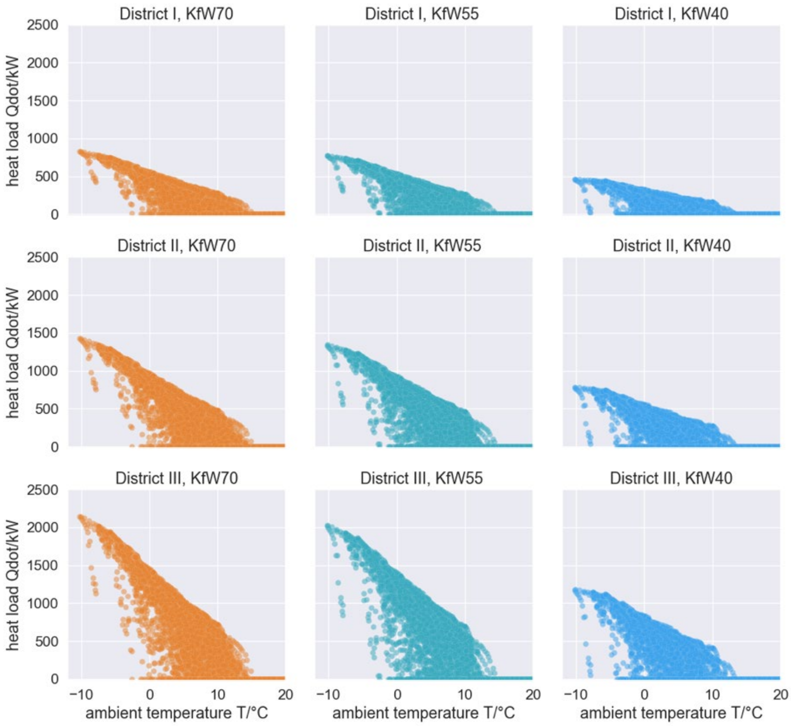


Figure 1: Resulting space heat load (net demand) of various building envelope standard and district composition

Plenary keynote

Poul Skjærbæk
Head of Offshore Innovation, Siemens Gamesa Renewable Energy

Offshore Wind Power & Electrofuels

Offshore wind power has in five years halved its electricity strike prices, while almost doubling turbine and windfarm size. The next disruptive step is for offshore wind to use its competitive cost-level and scalability potential, to enable commercially attractive electrofuel production. One of the potential energy carriers is Green Ammonia which has the potential to drastically reduce CO2 emissions in two sectors that are traditionally challenging, agriculture and transportation. In agriculture it can replace the annually consumed 180 million tons of black Ammonia, and in Global Shipping it can replace the annually consumed 300 million tons of fossil bunker fuel. Head of Offshore Innovation in Siemens Gamesa Renewable Energy, Poul Skjærbæk, will in this keynote discuss how the low price levels of offshore wind power combined with recent price drops in electrolysis equipment have the potential to make electrofuel production commercially possible.

Plenary keynote

Jean-Michel Glachant
Director, Florence School of Regulation

The second wave of electricity system revolutions: Peer-2-Peer and Communities

I was already researching on industry forms, 30 years ago, when a first electricity system revolution started: open wholesale markets. It was said impossible since the creation of that industry, in the 1880's. I was myself thinking that it couldn't work, and decided to explain why, taking the newly created *Electricity Pool of England & Wales* as a case study. It took me a full year to understand why this market was working, and why I was wrong.

Today, 30 years later, the rearguard of open wholesale markets has swallowed B2C, with the opening of retail markets, and C2B, with the creation of aggregators. But nothing else could happen because, you know, electricity is electricity, and Kirchhoff Laws are Kirchhoff Laws…

Well I am very sorry for this rearguard but something else is already happening: P2P and Communities.

In P2P, small players, each of the size of a consumption unit, can directly exchange goods and services, thanks to the digitalization of trade relations: of search, delivery, and settlement. It is where we see "*platforms*"; that can use "*blockchains*" and "*smart contracts*", or not.

In Communities, small players can regroup to invest together, to manage assets together, to define special rules of behaviour and of sharing that will procure them certain services with particular features - that an isolated individual cannot deliver, that an open market cannot guarantee.

This revolution of deeper decentralization of the electricity system is started and will not stop. We only do not know all its multifaceted dimensions, its speed, its deepness, its limits.

Plenary keynote

Søren Hermansen
Samsø Energiakademi

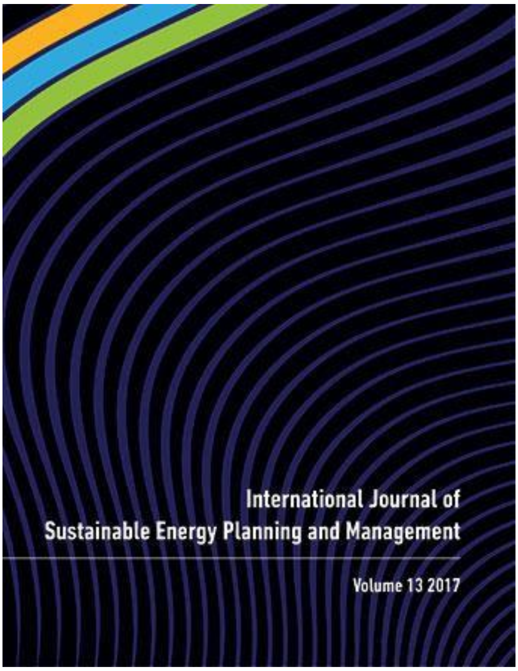
Resilient communities – Samsø island - a living lab for community ownership

Leadership development
Going from “business as usual” to a direct change of energy systems, takes serious leadership skills. Development has often been focusing on technology and financing until we realized that the real barrier was leadership and knowledge in practice. This means that lasting change and development needs educated and skilled leaders who can balance cultural resistance with evolutionary development. We train frontrunners and entrepreneurs leadership skills.

Capacity building
In the rural part of the world we today see a real lack of capacity and competences. Most young and educated people as well as start up companies move away from the rural area and migrate to the cities and stay there. We need to change that pattern and make sure we have the needed capacity to make real change. We either need to build capacity or at least to know where to search for the competences needed for change. In the program we will make sure the network is active and we create a “bank of local knowledge” that is an open source for developers.

Community power movement
Going from UN development goals to local action seems to be so difficult that in most places nothing really happens. Why? If there is any consensus at all in the world it has to be around the UN development goals. But it is at the same time so much top down and apparently too academic for ordinary people to translate and in cooperate in daily life that we miss the connection.
To understand your role in action you need to be able to “see” and understand your community and the role you play to be active and engaged as a citizen.
We need to talk about social capacity and engaged ownership – both physical and mental. We need all hands on deck if we want real change!!

International Journal of Energy Planning and Management, Vol 12 + 13 (2017)



Smart district heating and electrification
Poul Alberg Østergaard, Henrik Lund

Comparison of Low-temperature District Heating Concepts in a Long-Term Energy System Perspective
Rasmus Lund, Dorte Skaarup Østergaard, Xiaochen Yang, Brian Vad Mathiesen

Flexible use of electricity in heat-only district heating plants
Erik Trømborg

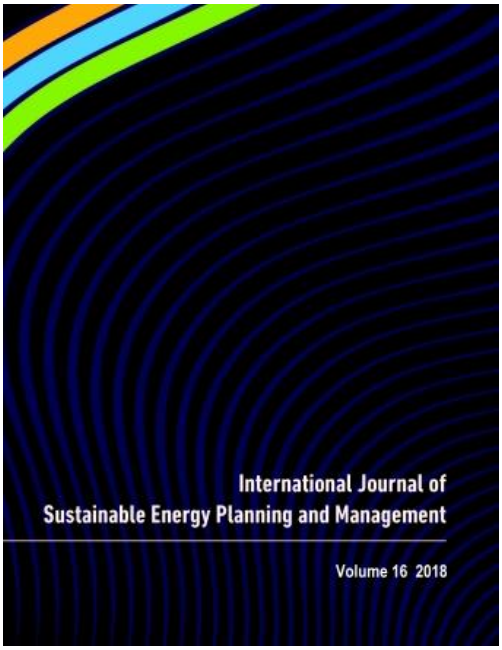
Innovative Delivery of Low Temperature District Heating System
Anton Ivanov Ianakiev

Techno-Economic Assessment of Active Latent Heat Thermal Energy Storage Systems with Low-Temperature District Heating
Jose Fiacro Castro Flores, Alberto Rossi Espagnet, Justin NingWei Chiu, Viktoria Martin, Bruno Lacarrère

Energy scheduling model to optimize transition routes towards 100% renewable urban districts
Richard van Leeuwen

Customer perspectives on district heating price models
Kerstin Sernhed

International Journal of Energy Planning and Management, Vol 16 (2018)



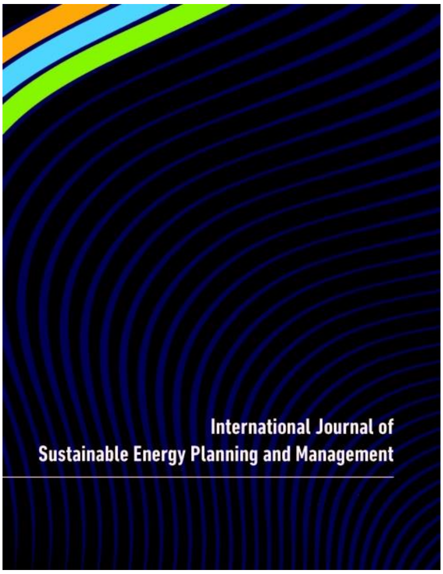
A spatial approach for future-oriented heat planning in urban areas
Jürgen Knies

Economic incentives for flexible district heating in the Nordic countries
Daniel Møller Sneum, Eli Sandberg

Economic comparison of low-temperature and ultra-low-temperature district heating for new building developments with low heat demand densities in Germany
Isabelle Best

Development of an empirical method for determination of thermal conductivity and heat loss for pre-insulated plastic bonded twin pipe systems
Georg Konrad Schuchardt

International Journal of Energy Planning and Management, Vol 20 (2019)



Developments in 4th generation district heating
Poul Alberg Østergaard, Henrik Lund, Brian Vad Mathiesen

A multi-objective optimization analysis to assess the potential economic and environmental benefits of distributed storage in district heating networks: a case study
Roberta Roberto, Raffaele De Iulio, Marialaura Di Somma, Giorgio Graditi, Giambattista Guidi, Michel Noussan

Development of a user-friendly mobile app for the national level promotion of the 4th generation district heating
Anna Volkova, Eduard Latõšov, Vladislav Mašatin, Andres Siirde

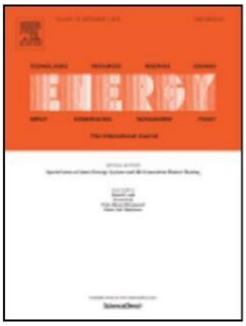
Method for addressing bottleneck problems in district heating networks
Lisa Brange, Kerstin Sernhed, Marcus Thern

Classification through analytic hierarchy process of the barriers in the revamping of traditional district heating networks into low temperature district heating: an Italian case study
Marco Pellegrini, Augusto Bianchini, Alessandro Guzzini, Cesare Saccani

Modelling framework for integration of large-scale heat pumps in district heating using low-temperature heat sources
Henrik Pieper, Vladislav Mašatin, Anna Volkova, Torben Ommen, Brian Elmegaard, Wiebke Brix Markussen

Energy, Volume 110 (1 September 2016)
Special issue on Smart Energy Systems and 4th Generation District Heating
Selected papers from the 1st International Conference on Smart Energy Systems and 4th Generation District Heating

Edited by Henrik Lund, Neven Duic, Poul Alberg Østergaard and Brian Vad Mathiesen



Smart energy systems and 4th generation district heating
Henrik Lund, Neven Duic, Poul Alberg Østergaard, Brian Vad Mathiesen

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Benedetto Nastasi, Gianluigi Lo Basso

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Dietmar Schüwer, Christine Krüger, Frank Merten, Arjuna Nebel

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Christoffer Lythcke-Jørgensen, Adriano Viana Ensinas, Marie Münster, Fredrik Haglind

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Weiming Xiong, Yu Wang, Brian Vad Mathiesen, Xiliang Zhang

Decentralized substations for low-temperature district heating with no Legionella risk, and low return temperatures
Xiaochen Yang, Hongwei Li, Svend Svendsen

Replacing critical radiators to increase the potential to use low-temperature district heating – A case study of 4 Danish single-family houses from the 1930s
Dorte Skaarup Østergaard, Svend Svendsen

System dynamics model analysis of pathway to 4th generation district heating in Latvia
Jelena Ziemele, Armands Gravelsins, Andra Blumberga, Girts Vigants, Dagnija Blumberga

Complex thermal energy conversion systems for efficient use of locally available biomass
Jacek Kalina

Current and future prospects for heat recovery from waste in European district heating systems: A literature and data review
Urban Persson, Marie Münster

Mapping of potential heat sources for heat pumps for district heating in Denmark
Rasmus Lund, Urban Persson

Industrial surplus heat transportation for use in district heating
J.NW. Chiu, J. Castro Flores, V. Martin, B. Lacarrière

European space cooling demands
Sven Werner

Optimal planning of heat supply systems in urban areas
Valery A. Stennikov, Ekaterina E. Iakimetc

Ringkøbing-Skjern energy atlas for analysis of heat saving potentials in building stock
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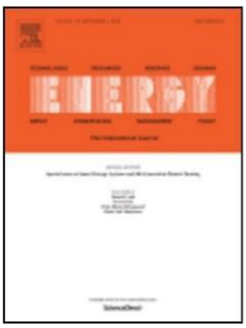
Edited by Henrik Lund



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Fabian Levihn

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Gerald Schweiger, Jonatan Rantzer, Karin Ericsson, Patrick Lauenburg

Comparison of distributed and centralised integration of solar heat in a district heating system
M. Rämä, S. Mohammadi

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Ashreeta Prasanna, Viktor Dorer, Nadège Vetterli

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Sven Werner

Bottlenecks in district heating networks and how to eliminate them – A simulation and cost study
Lisa Brange, Patrick Lauenburg, Kerstin Sernhed, Marcus Thern

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Jelena Ziemele, Armands Gravelsins, Andra Blumberga, Dagnija Blumberga

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Raimonda Soloha, Ieva Pakere, Dagnija Blumberga

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Carlo Winterscheid, Jan-Olof Dalenbäck, Stefan Holler

District heating and cooling systems – Framework for Modelica-based simulation and dynamic optimization
Gerald Schweiger, Per-Ola Larsson, Fredrik Magnusson, Patrick Lauenburg, Stéphane Velut

Smart energy and smart energy systems
Henrik Lund, Poul Alberg Østergaard, David Connolly, Brian Vad Mathiesen

Performance of ultra low temperature district heating systems with utility plant and booster heat pumps
Torben Ommen, Jan Eric Thorsen, Wiebke Brix Markussen, Brian Elmegaard

The impact of changes in the geometry of a radial microturbine stage on the efficiency of the micro CHP plant based on ORC
Tomasz Z. Kaczmarczyk, Grzegorz Żywica, Eugeniusz Ihnatowicz

Survey of radiator temperatures in buildings supplied by district heating
M. Jangsten, J. Kensby, J.-O. Dalenbäck, A. Trüschel

Dynamic modelling of local low-temperature heating grids: A case study for Norway
Hanne Kauko, Karoline Husevåg Kvalsvik, Daniel Rohde, Armin Hafner, Natasa Nord

Sensitivity analysis of heat losses in collective heat distribution systems using an improved method of EPBD calculations
Julio Efrain Vaillant Rebollar, Eline Himpe, Jelle Laverge, Arnold Janssens

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Mikko Wahlroos, Matti Pärssinen, Jukka Manner, Sanna Syri

Thermal performance of a solar assisted horizontal ground heat exchanger
Yasameen Al-Ameen, Anton Ianakiev, Robert Evans

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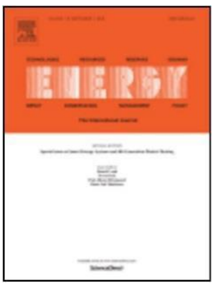

Cost-benefit analysis of district heating systems using heat from nuclear plants in seven European countries
Martin Leurent, Pascal Da Costa, Miika Rämä, Urban Persson, Frédéric Jasserand

The joint effect of centralised cogeneration plants and thermal storage on the efficiency and cost of the power system
Juan Pablo Jiménez Navarro, Konstantinos C. Kavvadias, Sylvain Quoilin, Andreas Zucker

Multi-objective optimization algorithm coupled to EnergyPLAN software: The EPLANopt model
Matteo Giacomo Prina, Marco Cozzini, Giulia Garegnani, Giampaolo Manzolini, Wolfram Sparber

Technical assessment of electric heat boosters in low-temperature district heating based on combined heat and power analysis
Hanmin Cai, Shi You, Jiawei Wang, Henrik W. Bindner, Sergey Klyapovskiy

Methodology for evaluating the transition process dynamics towards 4th generation district heating networks
Anna Volkova, Vladislav Mašatin, Andres Siirde

Balancing demand and supply: Linking neighborhood-level building load calculations with detailed district energy network analysis models
Samuel Letellier-Duchesne, Shreshth Nagpal, Michaël Kummert, Christoph Reinhart

A theoretical benchmark for bypass controllers in a residential district heating network
Annelies Vandermeulen, Bram van der Heijde, Dieter Patteeuw, Dirk Vanhoudt, Lieve Helsen

The impact of global warming and building renovation measures on district heating system techno-economic parameters
I. Andrić, J. Fournier, B. Lacarrière, O. Le Corre, P. Ferrão

Synthesis of recent Swedish district heating research
Kerstin Sernhed, Kristina Lygnerud, Sven Werner

Dynamic modeling of local district heating grids with prosumers: A case study for Norway
Hanne Kauko, Karoline Husevåg Kvalsvik, Daniel Rohde, Natasa Nord, Åmund Utne

Risk assessment of industrial excess heat recovery in district heating systems
Kristina Lygnerud, Sven Werner

Spatiotemporal and economic analysis of industrial excess heat as a resource for district heating
Fabian Bühler, Stefan Petrović, Fridolin Müller Holm, Kenneth Karlsson, Brian Elmegaard

Dynamic exergoeconomic analysis of a heat pump system used for ancillary services in an integrated energy system
Wiebke Meesenburg, Torben Ommen, Brian Elmegaard

Challenges and potentials for low-temperature district heating implementation in Norway
Natasa Nord, Elise Kristine Løve Nielsen, Hanne Kauko, Tymofii Tereshchenko

Recycling construction and industrial landfill waste material for backfill in horizontal ground heat exchanger systems
Yasameen Al-Ameen, Anton Ianakiev, Robert Evans

Pathway and restriction in district heating systems development towards 4th generation district heating
Jelena Ziemele, Einars Cilinskis, Dagnija Blumberga

Technical and economic feasibility of sustainable heating and cooling supply options in southern European municipalities-A case study for Matosinhos, Portugal
Eftim Popovski, Tobias Fleiter, Hugo Santos, Vitor Leal, Eduardo Oliveira Fernandes

Improving the performance of booster heat pumps using zeotropic mixtures
B. Zühlsdorf, W. Meesenburg, T.S. Ommen, J.E. Thorsen, W.B. Markussen, B. Elmegaard

Solar power and heat production via photovoltaic thermal panels for district heating and industrial plant
Ieva Pakere, Dace Lauka, Dagnija Blumberga

Solar facade module for nearly zero energy building
Ruta Vanaga, Andra Blumberga, Ritvars Freimanis, Toms Mols, Dagnija Blumberga

Thermal load forecasting in district heating networks using deep learning and advanced feature selection methods
Gowri Suryanarayana, Jesus Lago, Davy Geysen, Piotr Aleksiejuk, Christian Johansson

Multi-criteria analysis of storages integration and operation solutions into the district heating network of Aarhus – A simulation case study
C. Marguerite, G.B. Andresen, M. Dahl

Impact of building geometry description within district energy simulations
Ina De Jaeger, Glenn Reynders, Yixiao Ma, Dirk Saelens

Simulation based evaluation of large scale waste heat utilization in urban district heating networks: Optimized integration and operation of a seasonal storage
M. Köfinger, R.R. Schmidt, D. Basciotti, O. Terreros, I. Baldvinsson, J. Mayrhofer, S. Moser, R. Tichler, H. Pauli

Investigation of hydraulic imbalance for converting existing boiler based buildings to low temperature district heating
Asad Ashfaq, Anton Ianakiev

The electricity market in a renewable energy system
Søren Djørup, Jakob Zinck Thellufsen, Peter Sorknæs

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Gerald Schweiger, Richard Heimrath, Basak Falay, Keith O'Donovan, Peter Nageler, Reinhard Pertschy, Georg Engel, Wolfgang Streicher, Ingo Leusbrock

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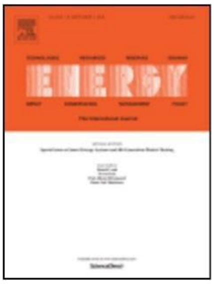
Henrik Lund, Neven Duic, Poul Alberg Østergaard, Brian Vad Mathiesen

Energy (Last update 11 July 2019)

Special issue on Smart Energy Systems and 4th Generation District Heating

Selected papers from the 4th International Conference on Smart Energy Systems and 4th Generation District Heating

Edited by Prof. Henrik Lund



Lowering the pressure in district heating and cooling networks by alternating the connection of the expansion vessel
Tobias Sommer, Stefan Mennel, Matthias Sulzer

Compact physical model for simulation of thermal networks
Elisa Guelpa, Vittorio Verda

Heat Roadmap Europe: Heat distribution costs
Urban Persson, Eva Wiechers, Bernd Möller, Sven Werner

Cost efficiency of district heating for low energy buildings of the future
C.H. Hansen, O. Gudmundsson, N. Detlefsen

Small low-temperature district heating network development prospects
Anna Volkova, Igor Krupenski, Henrik Pieper, Aleksandr Ledvanov, Eduard Latõšov, Andres Siirde

Faults in district heating customer installations and ways to approach them: Experiences from Swedish utilities
Sara Månsson, Per-Olof Johansson Kallioniemi, Marcus Thern, Tijs Van Oevelen, Kerstin Sernhed

Individual temperature control on demand response in a district heated office building in Finland
Sonja Salo, Juha Jokisalo, Sanna Syri, Risto Kosonen

A framework for assessing the technical and economic potential of shallow geothermal energy in individual and district heating systems: A case study of Slovenia
Gašper Stegnar, D. Staničić, M. Česen, J. Čižman, S. Pestotnik, J. Prestor, A. Urbančič, S. Merše

Future district heating plant integrated with municipal solid waste (MSW) gasification for hydrogen production
Souman Rudra, Yohannes Kifle Tesfagaber

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Johannes Pelda, Stefan Holler

Demand side management in district heating networks: A real application
Elisa Guelpa, Ludovica Marincioni, Stefania Deputato, Martina Capone, Stefano Amelio, Enrico Pochettino, Vittorio Verda

Solar power in district heating. P2H flexibility concept
Armands Gravelsins, Ieva Pakere, Anrijs Tukulis, Dagnija Blumberga

A method for technical assessment of power-to-heat use cases to couple local district heating and electrical distribution grids
Benedikt Leitner, Edmund Widl, Wolfgang Gawlik, René Hofmann

An automated GIS-based planning and design tool for district heating: Scenarios for a Dutch city
Joseph Maria Jebamalai, Kurt Marlein, Jelle Laverge, Lieven Vandevelde, Martijn van den Broek

Storage influence in a combined biomass and power-to-heat district heating production plant
Nicolas Lamaison, Simon Collette, Mathieu Vallée, Roland Bavière

Trilemma of historic buildings: Smart district heating systems, bioeconomy and energy efficiency
Andra Blumberga, Ritvars Freimanis, Indra Muizniece, Kriss Spalvins, Dagnija Blumberga

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Special Issue "4th International Conference on Smart Energy Systems and 4th Generation District Heating"

Guest editor: Associate Prof. Karl Sperling

Economic Evaluation and Simulation for the Hasselt Case Study: Thermochemical District Network Technology vs. Alternative Technologies for Heating
Muhannad Delwati, Ahmed Ammar, Philipp Geyer

Design and Analysis of District Heating Systems Utilizing Excess Heat in Japan
Shin Fujii, Takaaki Furubayashi, Toshihiko Nakata

Integration of Flow Temperatures in Unit Commitment Models of Future District Heating Systems
Cynthia Boysen, Cord Kaldemeyer, Simon Hilpert, Ilja Tuschy

A Simplified Methodology for Existing Tertiary Buildings' Cooling Energy Need Estimation at District Level: A Feasibility Study of a District Cooling System in Marrakech
Saeid Charani Shandiz, Alice Denarie, Gabriele Cassetti, Marco Calderoni, Antoine Frein, Mario Motta

Is It Possible to Supply Norwegian Apartment Blocks with 4th Generation District Heating?
Øystein Rønneseth, Nina Holck Sandberg, Igor Sartori

Agent-Based Modeling of a Thermal Energy Transition in the Built Environment
Graciela del Carmen Nava Guerrero, Gijsbert Korevaar, Helle Hvid Hansen, Zofia Lukszo

Modelling Influential Factors of Consumption in Buildings Connected to District Heating Systems
Danica Maljkovic

District Power-To-Heat/Cool Complemented by Sewage Heat Recovery
Marcello Aprile, Rossano Scoccia, Alice Dénarié, Pál Kiss, Marcell Dombrovszky, Damian Gwerder, Philipp Schuetz, Peru Elguezabal, Beñat Arregi

Optimal Scheduling of Combined Heat and Power Generation Units Using the Thermal Inertia of the Connected District Heating Grid as Energy Storage
Lennart Merkert, Ashvar Abdoul Haime, Sören Hohmann

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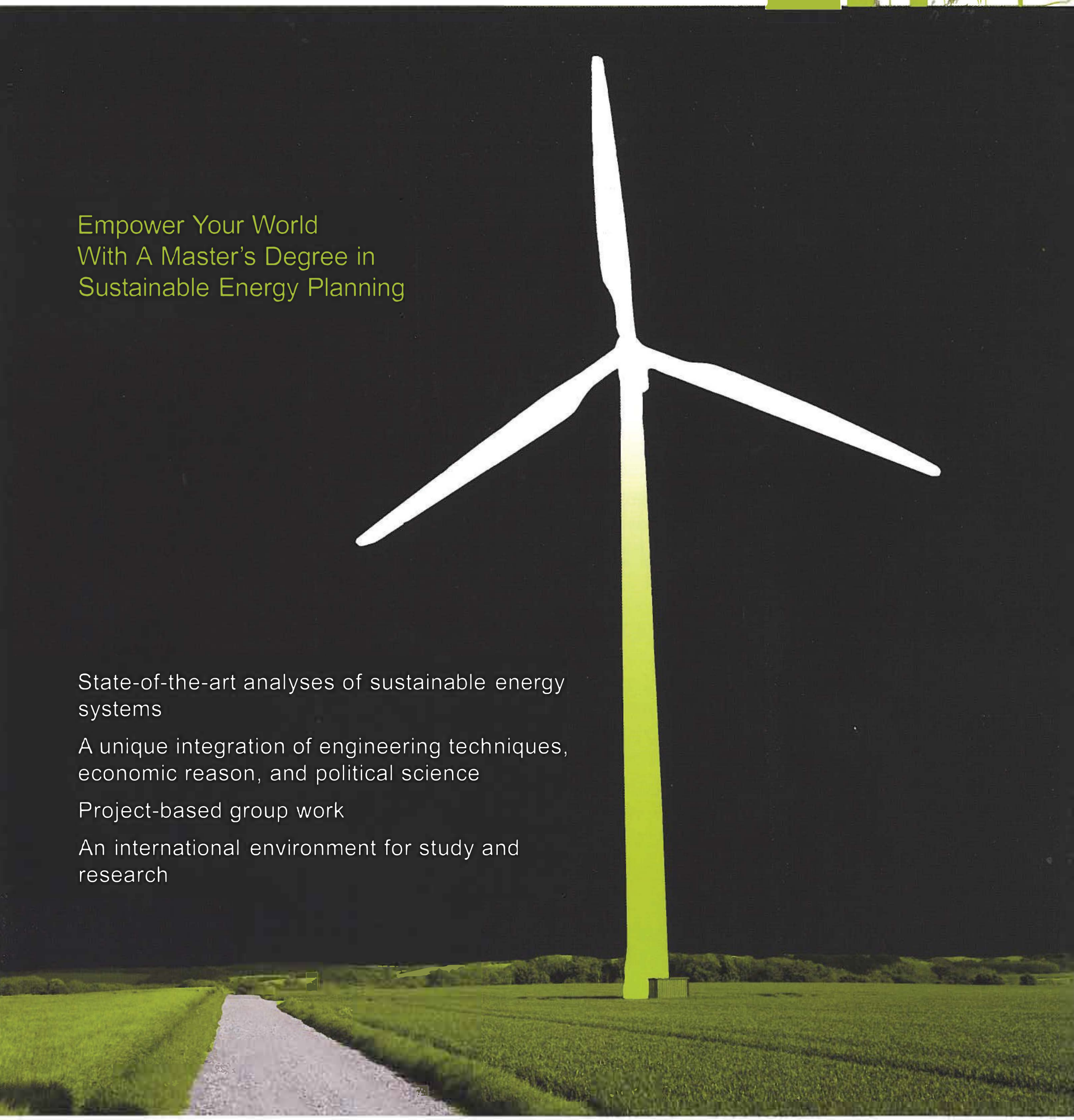

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